CHAPTER 8

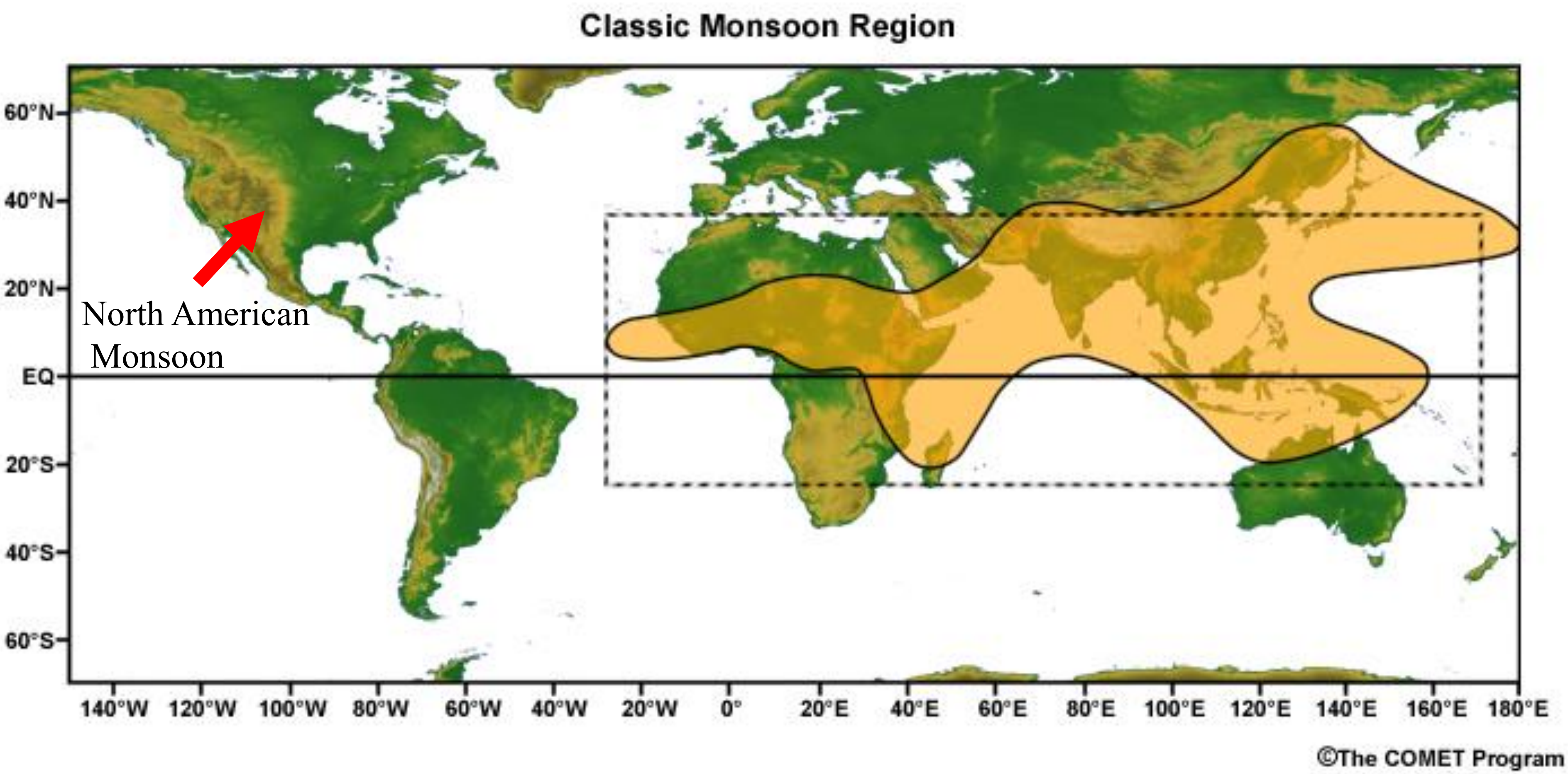
Insolation Control of Monsoons

Ruddiman uses correlations between monsoon history and Milankovitch orbital variations to illustrate their powerful roles in Earth's climate.

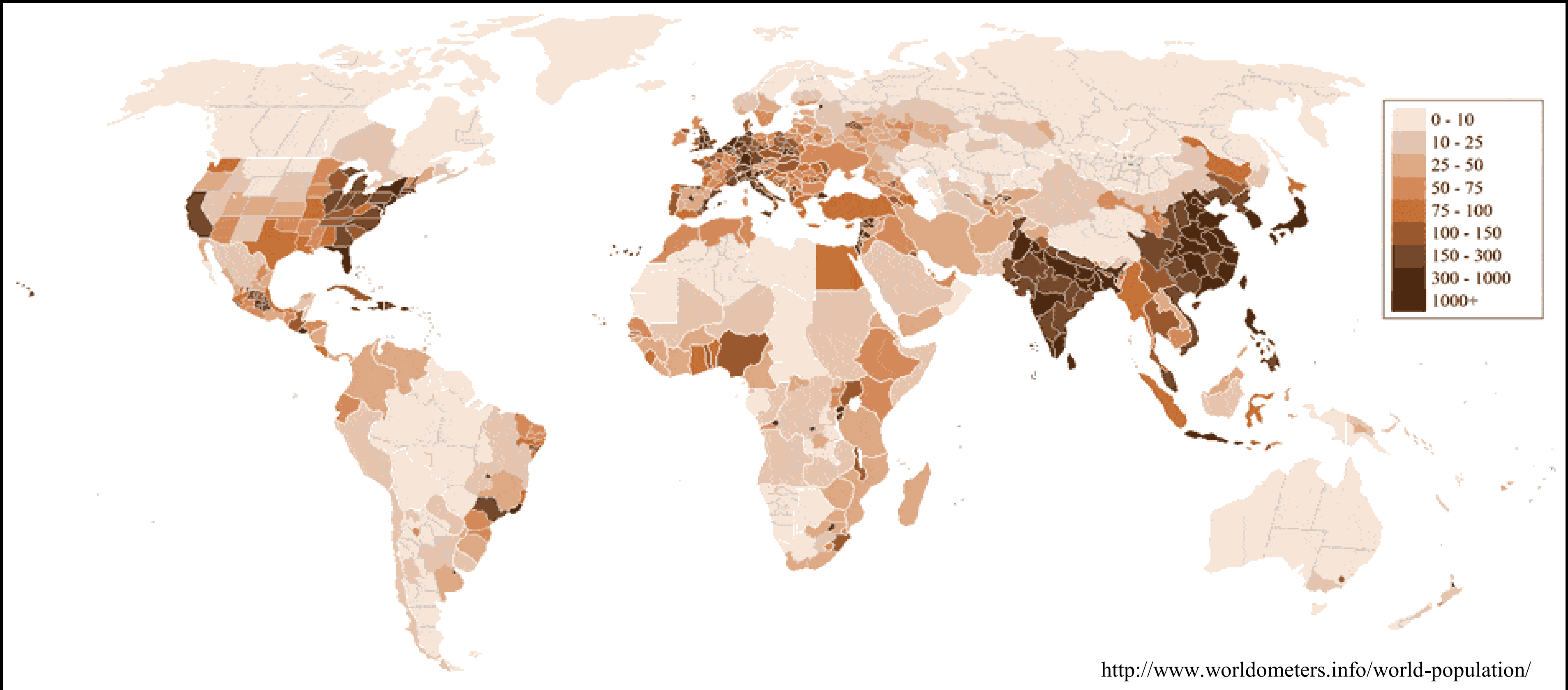
“Monsoon”

seasonally reversing wind regime
accompanied by changes in precipitation

Calcutta in July

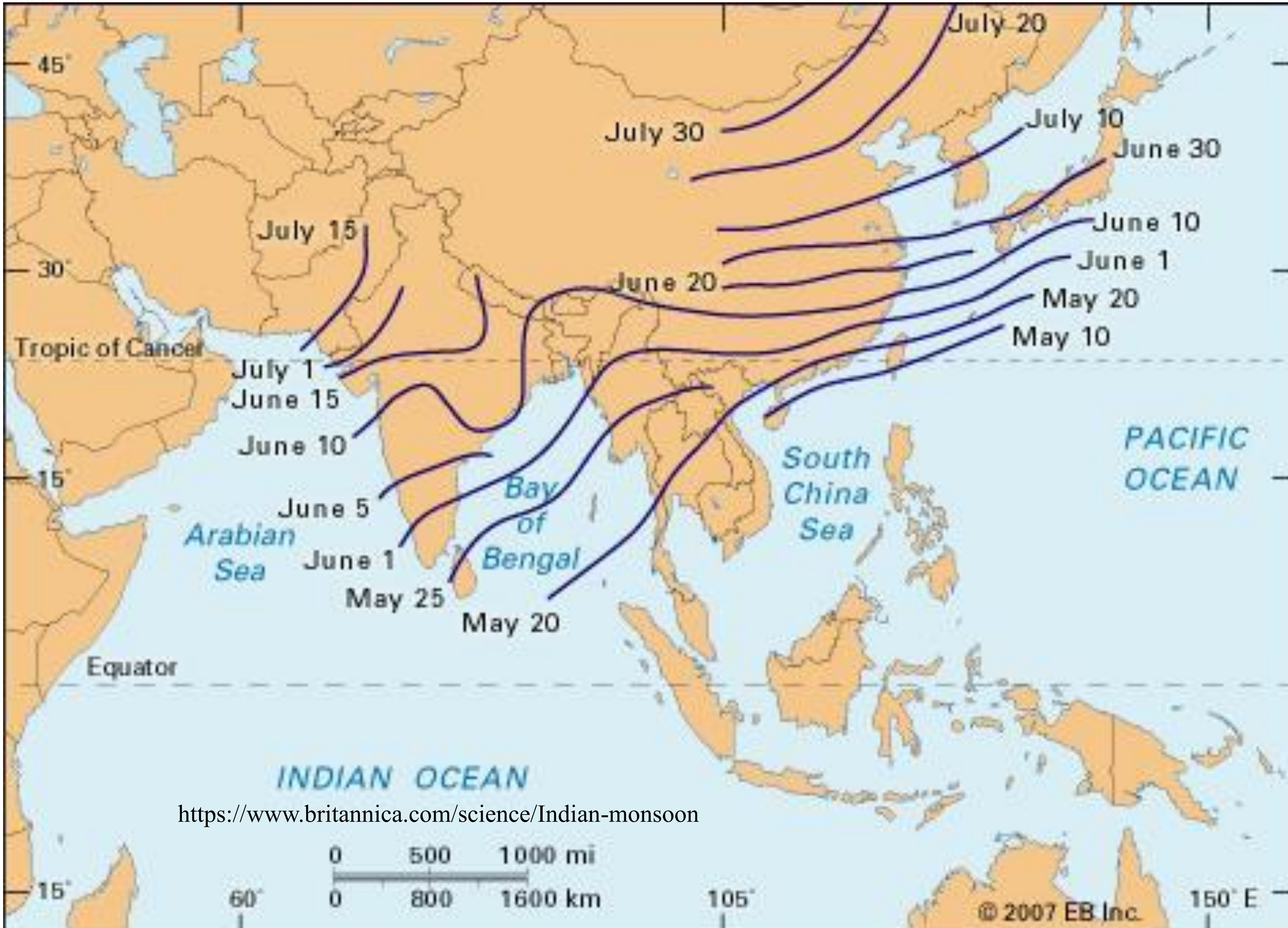

Classic Monsoon Region
60°N
40°N
20°N
EQ
20°S
40°S
60°S
140°W 120°W 100°W 80°W 60°W 40°W 20°W 0° 20°E 40°E 60°E 80°E 100°E 120°E 140°E 160°E 180°E
North American Monsoon
©The COMET Program

We are now 7.5 billion people,



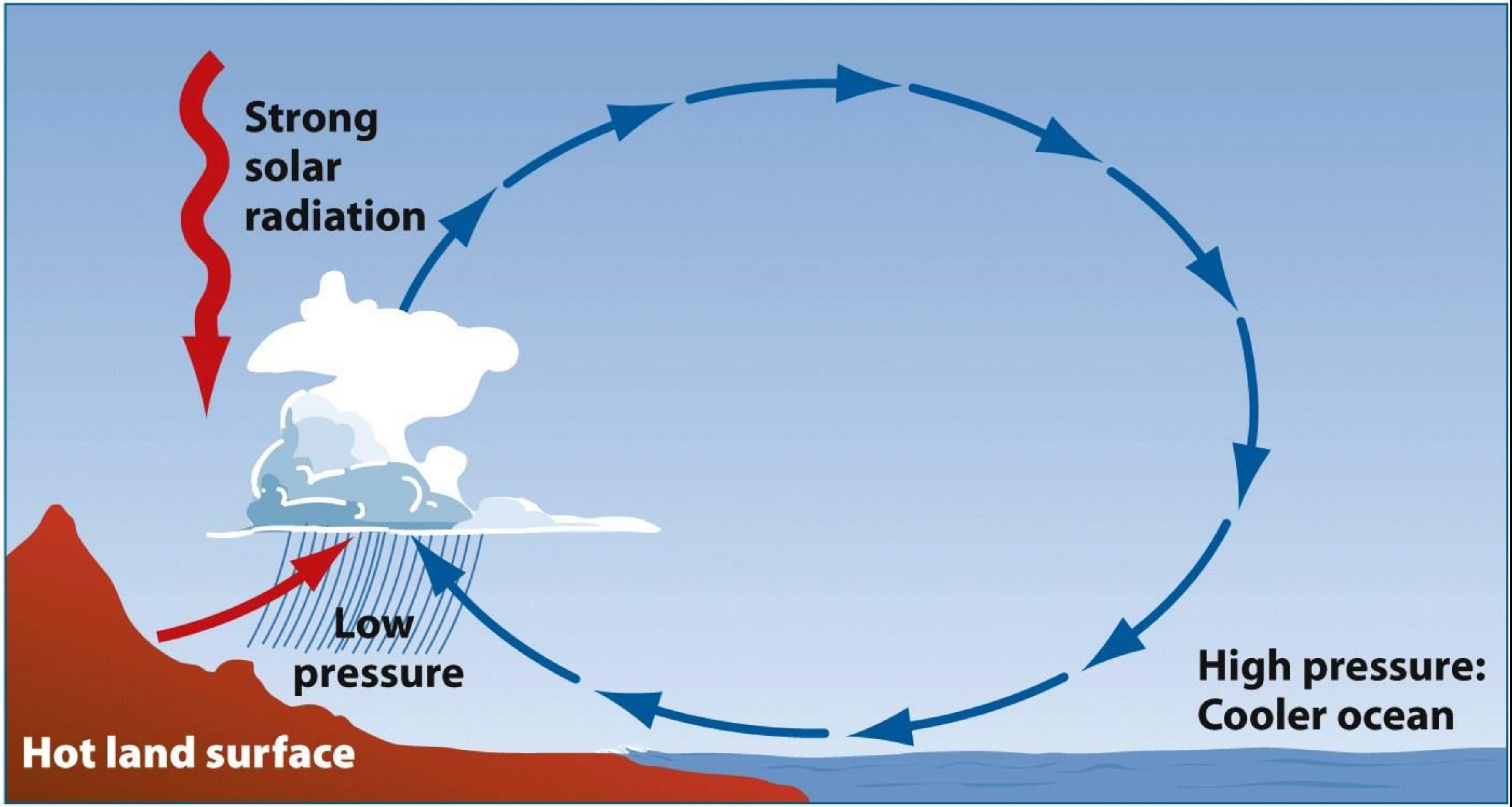
and many of us live in regions affected by the monsoons

date of onset of summer monsoon



https://www.britannica.com/science/Indian-monsoon

land warms faster than ocean



Summer monsoon

Figure 8-1
Earth's Climate: Past and Future, Second Edition

“giant cousin of an onshore breeze”

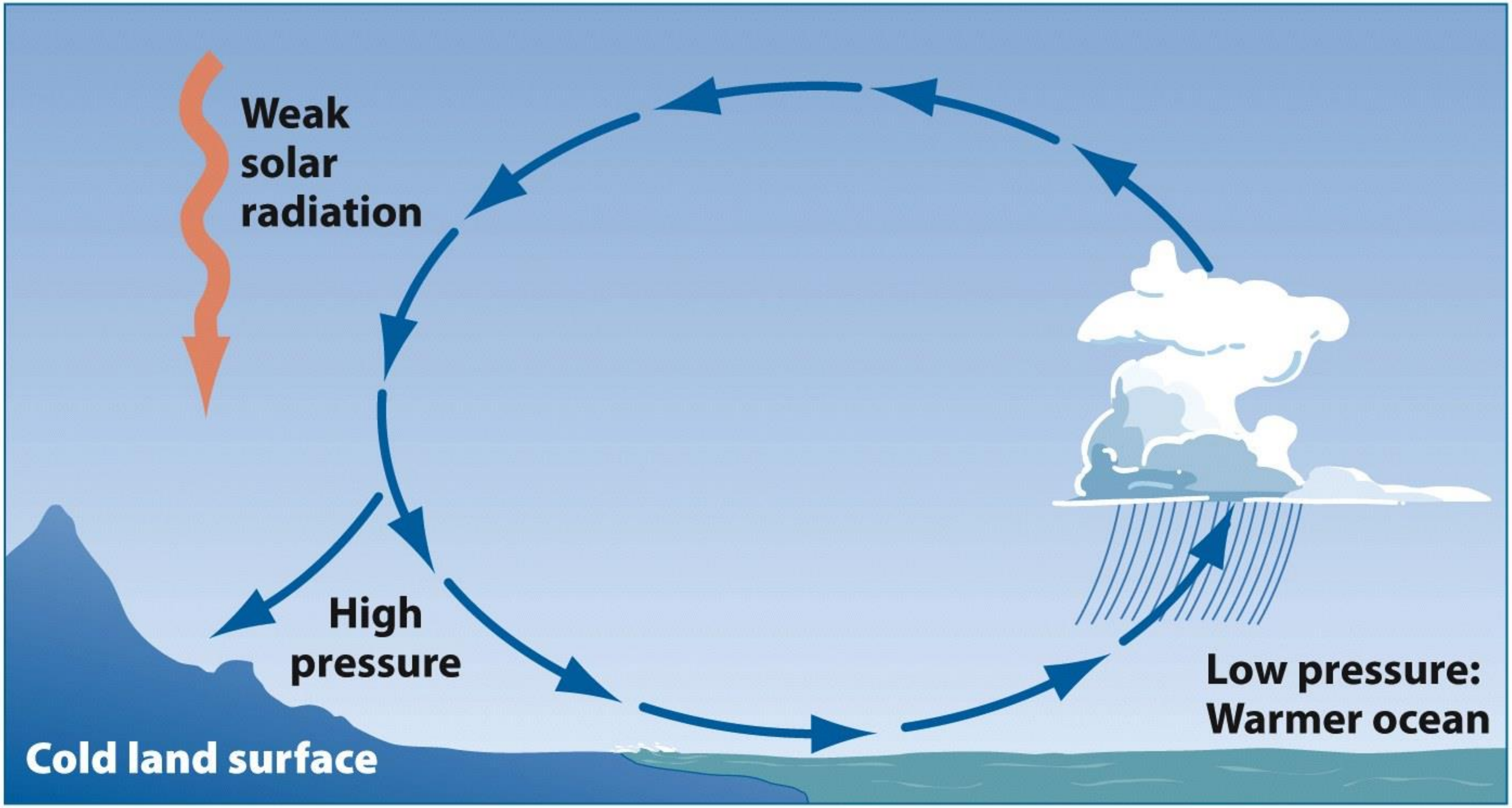
Nowadays, **monsoon** is used to describe seasonal changes in atmospheric circulation and precipitation associated with the asymmetric heating of land and sea.

Burkina Faso

Usually, the term **monsoon** is used to refer to the rainy phase of a seasonally-changing pattern, although technically there is also a dry phase (winter monsoon).

Yemen

rem: seasonal wind shift



Winter monsoon

Figure 8-1b
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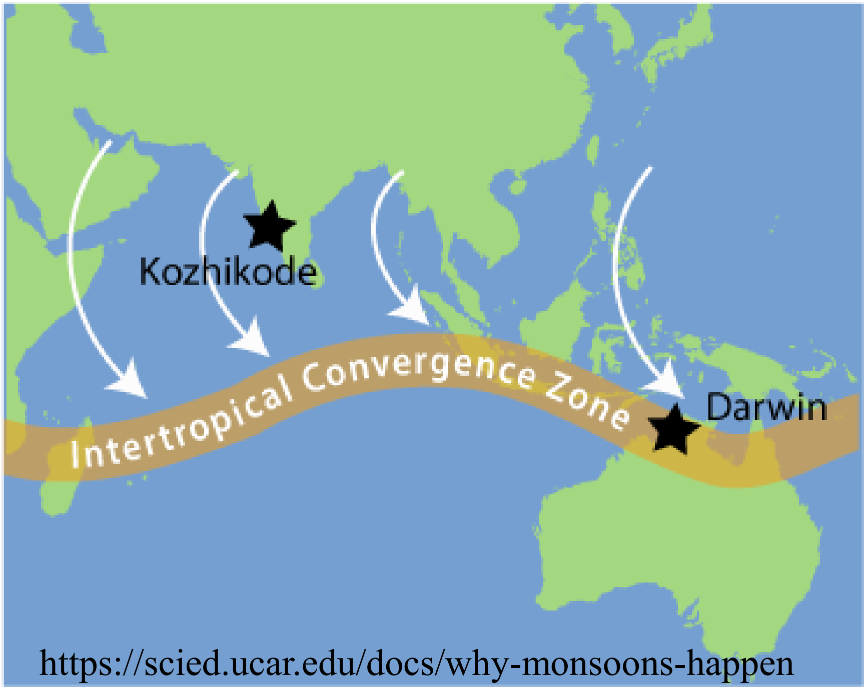
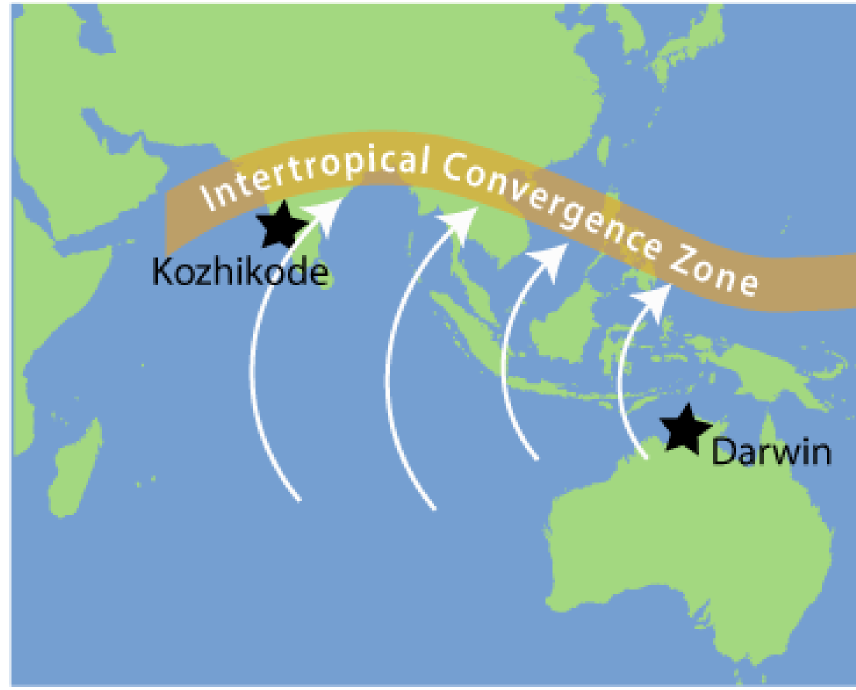
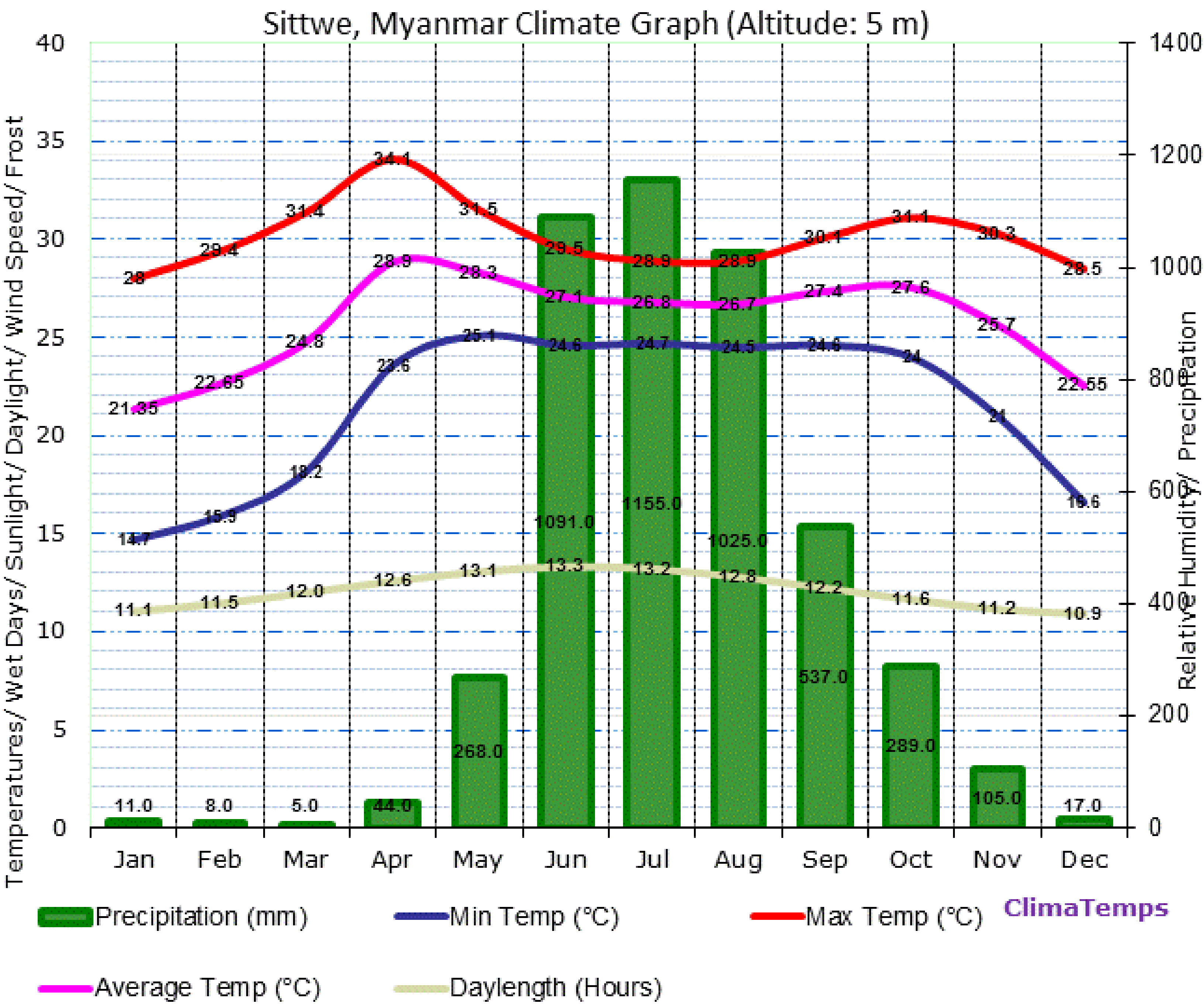
DECEMBER and JANUARY



https://scied.ucar.edu/docs/why-monsoons-happen

JUNE and JULY





Sittwe, Myanmar Climate Graph (Altitude: 5 m)
Temperatures/ Wet Days/ Sunlight/ Daylight/ Wind Speed/ Frost
Relative Humidity/ Precipitation
40
35
30
25
20
15
10
5
0
1400
1200
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
28
29.4
31.4
34.1
31.5
29.5
28.9
28.9
30.1
31.1
30.3
28.5
21.35
22.65
24.8
28.9
28.3
27.1
26.8
26.7
27.4
27.6
25.7
22.55
14.7
15.9
18.2
23.6
25.1
24.6
24.7
24.5
24.6
24
21
16.6
11.1
11.5
12.0
12.6
13.1
13.3
13.2
12.8
12.2
11.6
11.2
10.9
11.0
8.0
5.0
44.0
268.0
1091.0
1155.0
1025.0
537.0
289.0
105.0
17.0
Precipitation (mm)
Min Temp (°C)
Max Temp (°C)
ClimaTemps
Average Temp (°C)
Daylength (Hours)

Regions where monsoonal rainfall is important

India, Bangladesh, Pakistan, Nepal, Tibet: South Asian Monsoon (summer)

SE India and Sri Lanka: Northeast Asian Monsoon (autumn)

Phillipines, Indochina, China, Korea, Japan (South Asian Monsoon (summer)

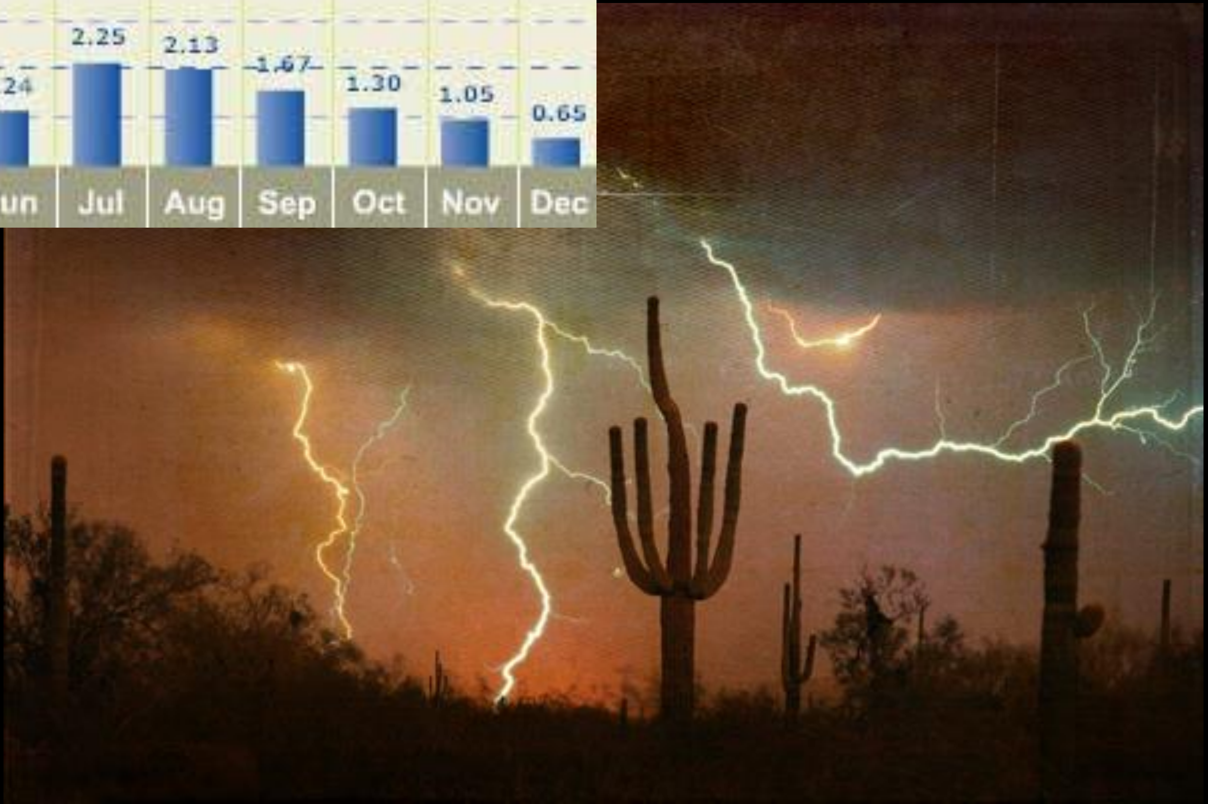
northern Australia: Indo-Australian Monsoon (summer)

subSaharan Africa: African monsoon (summer*)

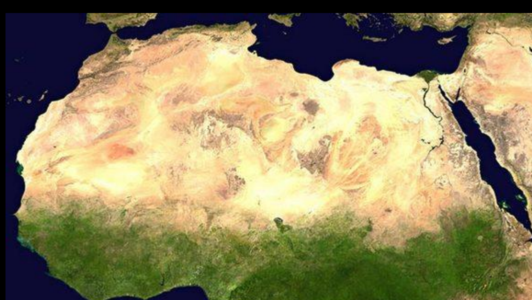
northern Mexico & SW USA: Mexican or N American Monsoon (summer)

northern Mexico, southwestern USA (North American Monsoon)

precipitation in Santa Fe



Changes in monsoon climates cause enormous ecosystem changes



Monsoons are a big deal sociopolitically

The South Asian Monsoon accounts for 80% of the rainfall in India and Pakistan.

Northern hemisphere summer

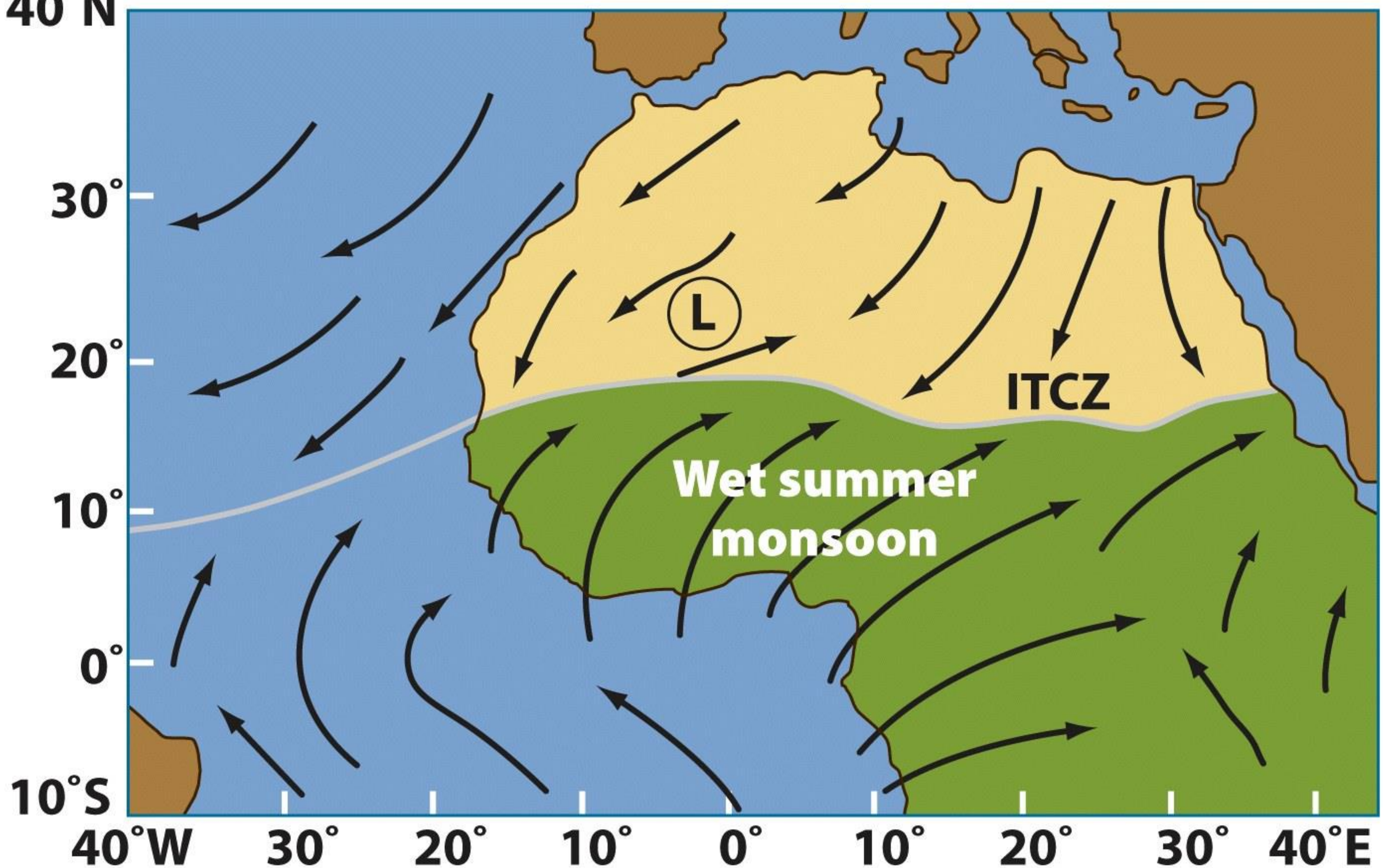


Figure 8-2a
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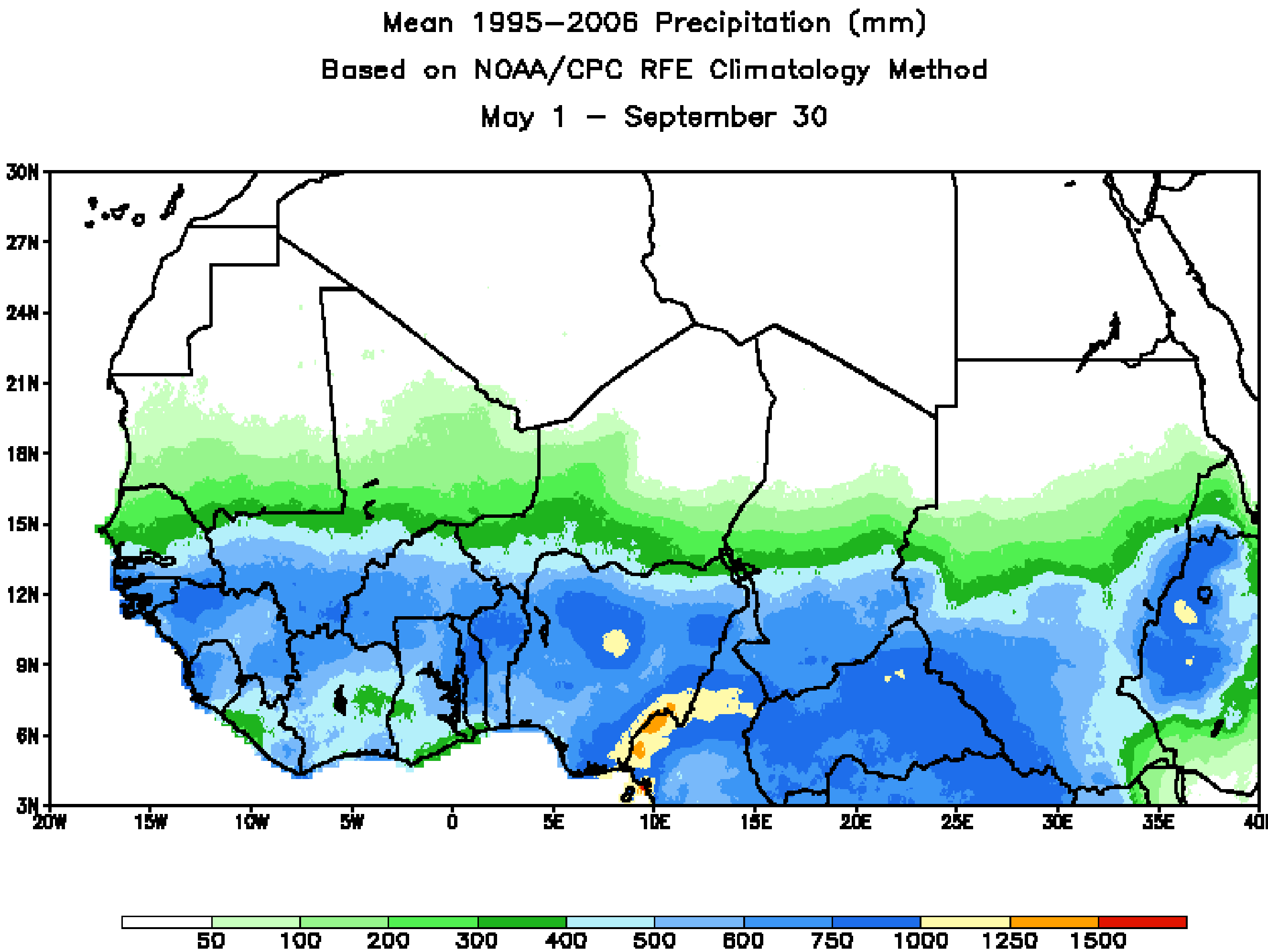
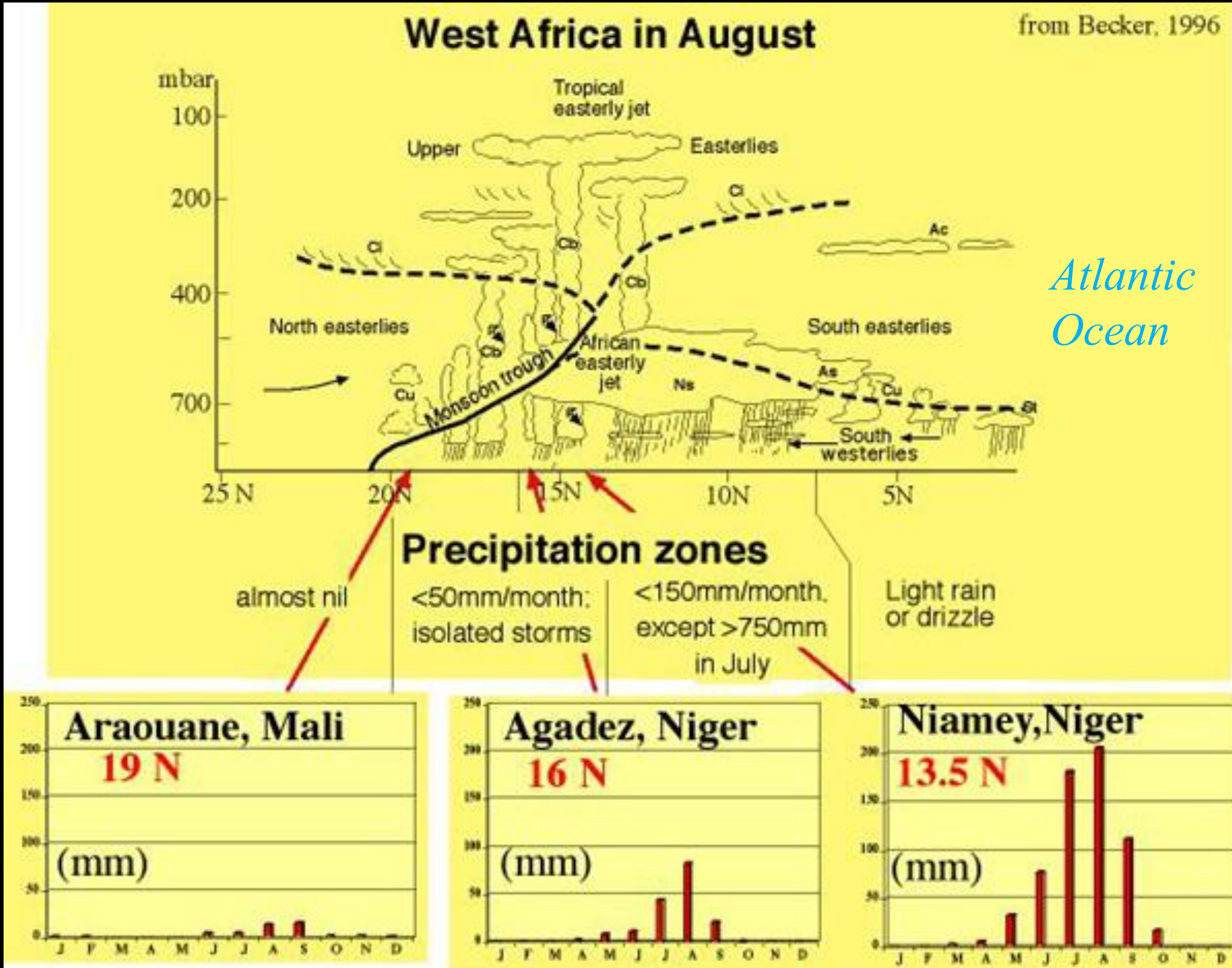


mean rainfall amount (mm) for the monsoon season (1 May – 30 September) in West Africa. Period 1995–2006. Based on NOAA/CPC Climatology Method Rainfall Estimates. Africa Rainfall Climatology (CPC ARC) Series.


West Africa in August
from Becker, 1996
mbar
100
200
400
700
Tropical easterly jet
Upper
Easterlies
Ci
Ac
Cb
North easterlies
South easterlies
Monsoon trough
African easterly jet
Ns
As
Cu
St
South westerlies
25 N
20N
15N
10N
5N
Atlantic Ocean
Precipitation zones
almost nil
<50mm/month: isolated storms
<150mm/month, except >750mm in July
Light rain or drizzle
Araouane, Mali
19 N
(mm)
Agadez, Niger
16 N
(mm)
Niamey,Niger
13.5 N
(mm)
J F M A M J J A S O N D

Northern hemisphere winter

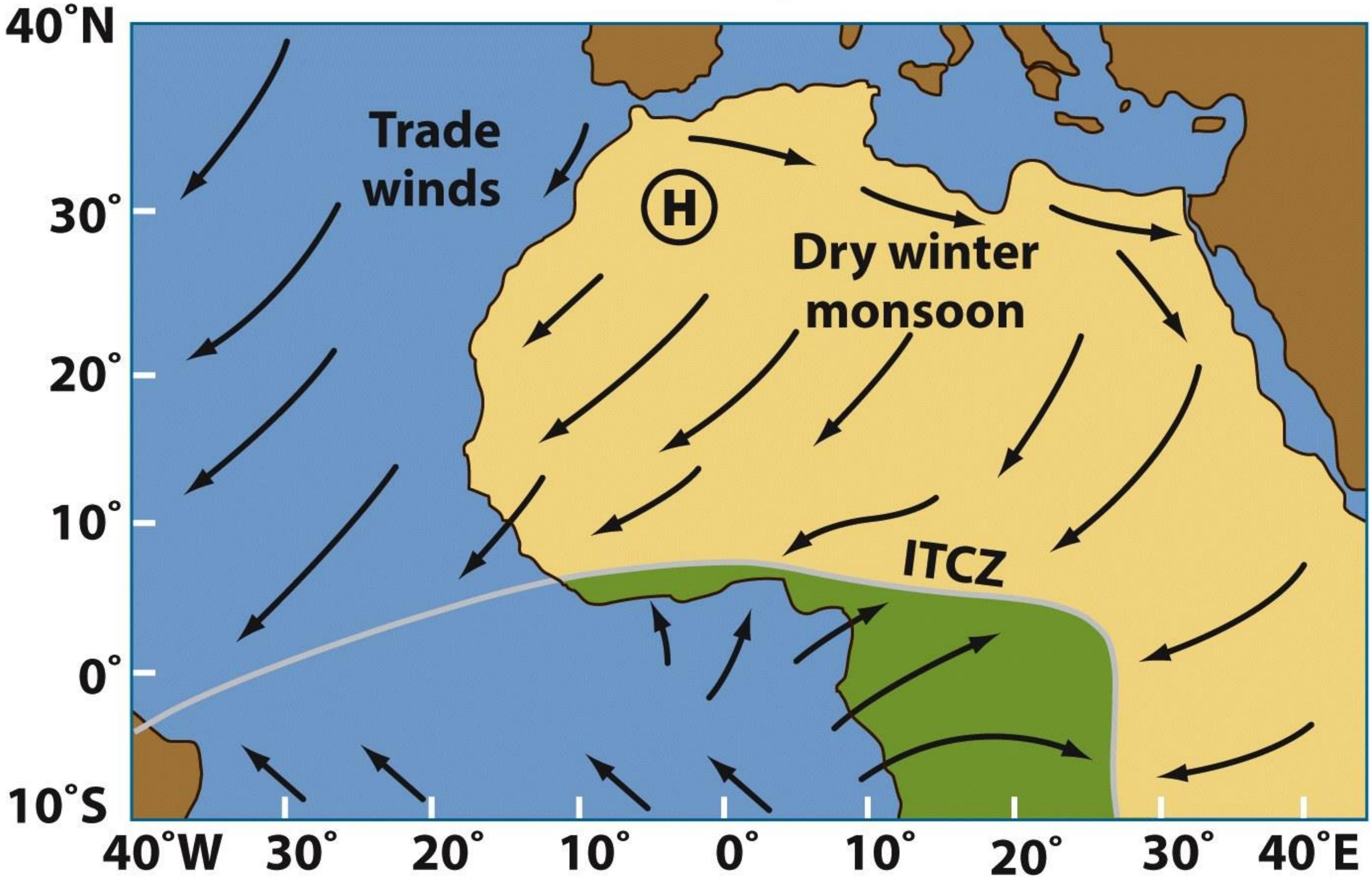
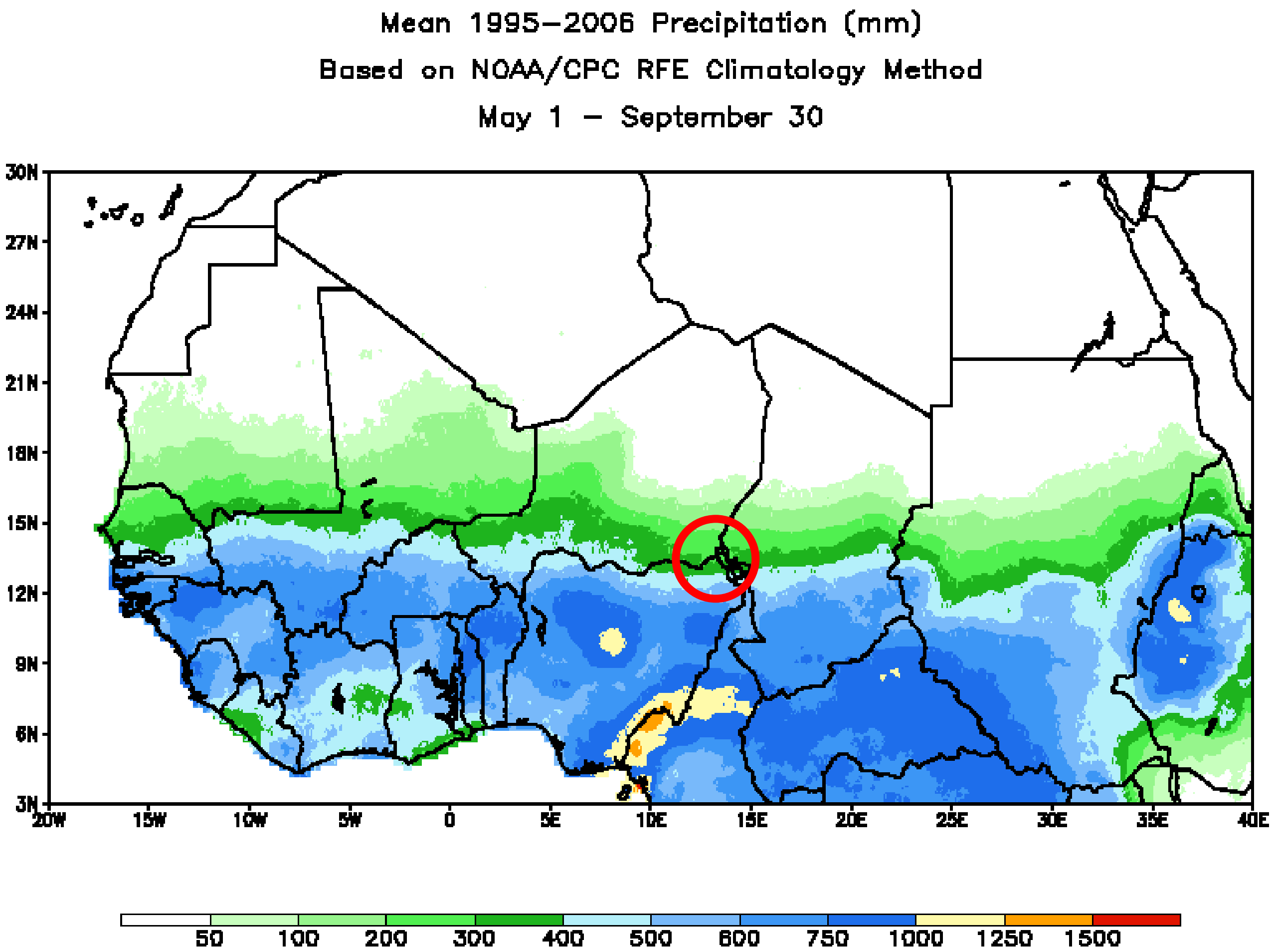
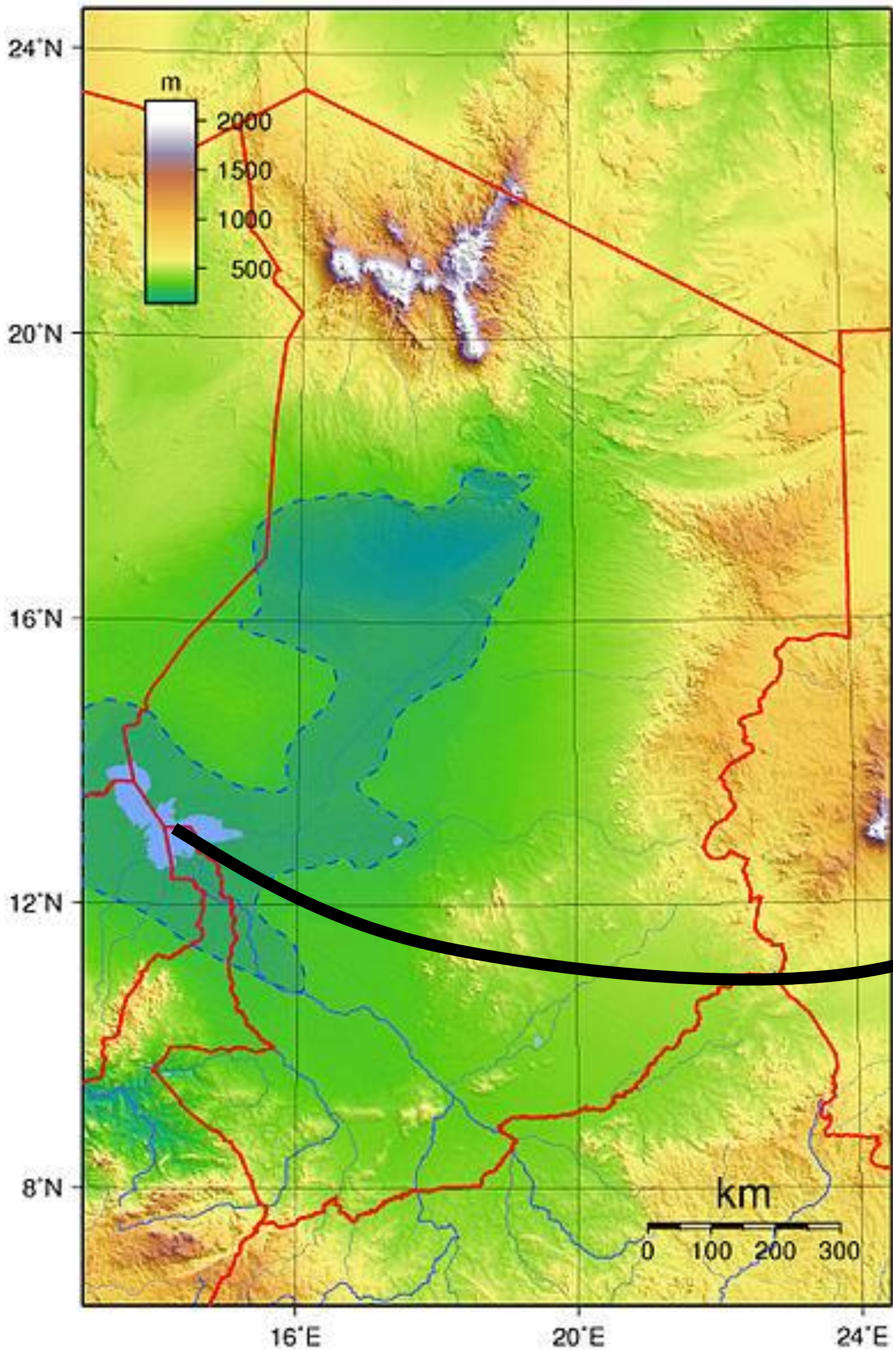


Figure 8-2b
Earth's Climate: Past and Future, Second Edition



Map showing mean rainfall amount (mm) for the monsoon season (1 May – 30 September) in West Africa. Period 1995–2006. Based on NOAA/CPC Climatology Method Rainfall Estimates. Africa Rainfall Climatology (CPC ARC) Series.



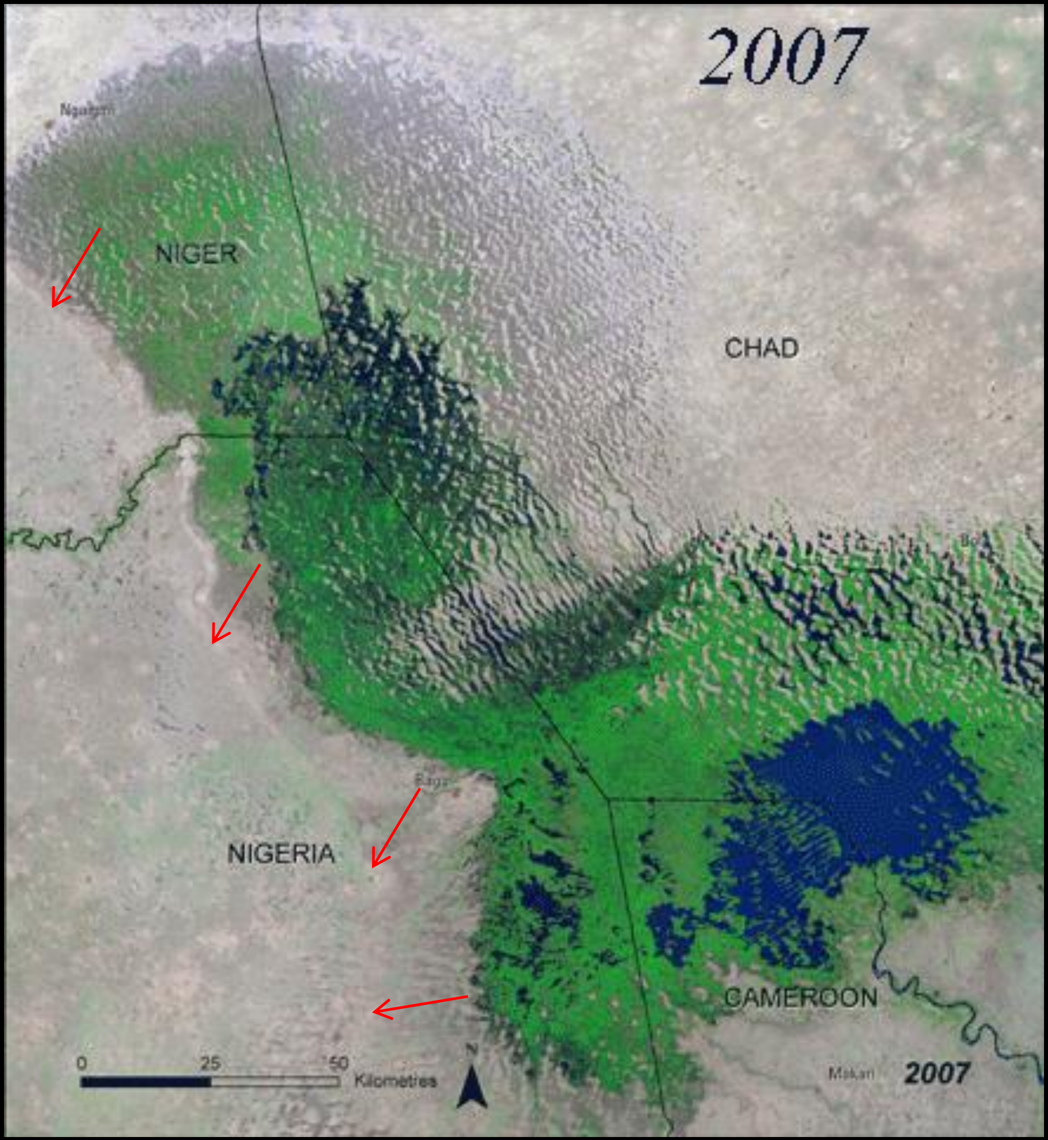
maximum extension of the Holocene "Lake Mega-Chad"

(light blue area limited by a blue dotted line)

Lake Chad provides water to more than 20 million people.

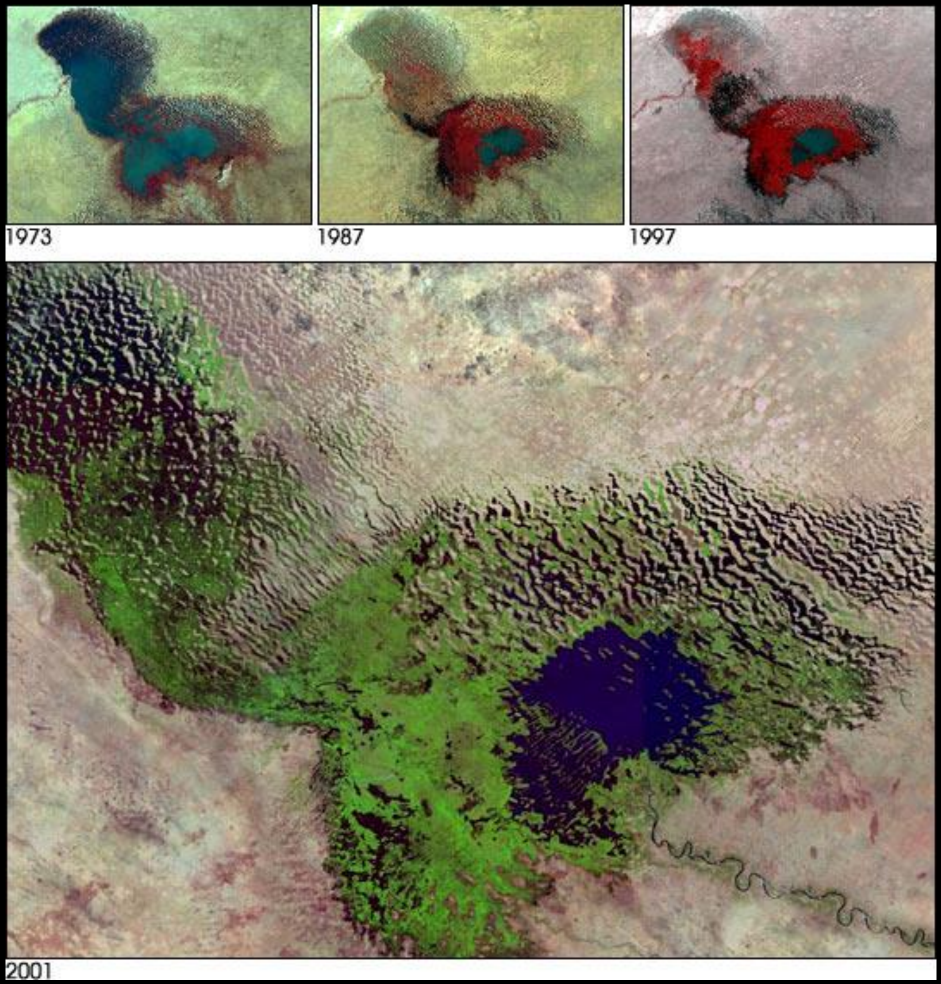
Wikipedia 2013

Lake Chad



arrows indicate paleo-shoreline

note stabilized sand dunes



Lake Chad today….

Journal Geophysical Research
2001
Coe and Foley:

"…30 percent decrease took place in the lake between 1966 and 1975. Irrigation only accounted for 5 percent of that decrease, with drier conditions accounting for the remainder. ..irrigation demands increased four-fold between 1983 and 1994, accounting for 50 percent of the additional decrease in the size of the lake. "

orbital monsoon hypothesis: changing solar insolation affects the strength and extent of monsoon systems

John Kutzbach
Professor Emeritus
Center for Climatic Research
University of Wisconsin

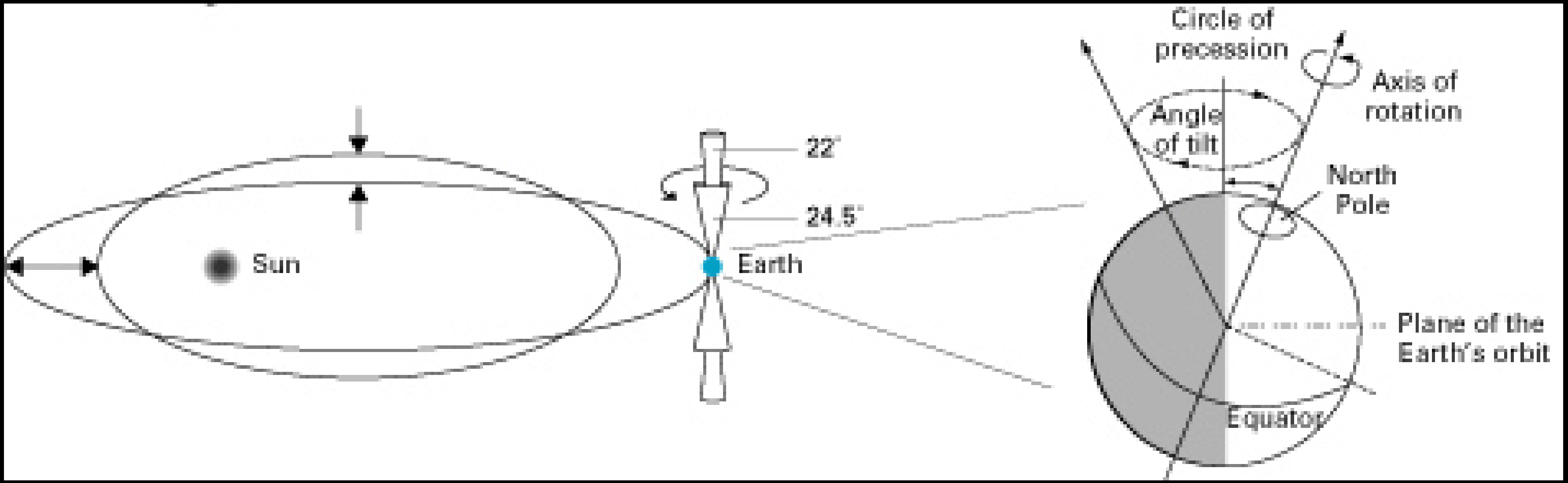
Rudolf Ferdinand Spitaler
Austrian Astronomer
1849-1946

Monsoon Climate of the Early Holocene: Climate Experiment with the Earth's Orbital Parameters for 9000 Years Ago

I conducted a sensitivity experiment by using solar radiation values for 9000 years B.P. in a low-resolution general circulation model in place of modern values. The model is global in extent and permits simulation of the regional atmospheric circulation and surface climates. Ocean surface temperature and land albedo must be specified.

JOHN E. KUTZBACH
Center for Climatic Research and
Department of Meteorology, University of Wisconsin, Madison 53706

eccentricity obliquity precession of equinoxes

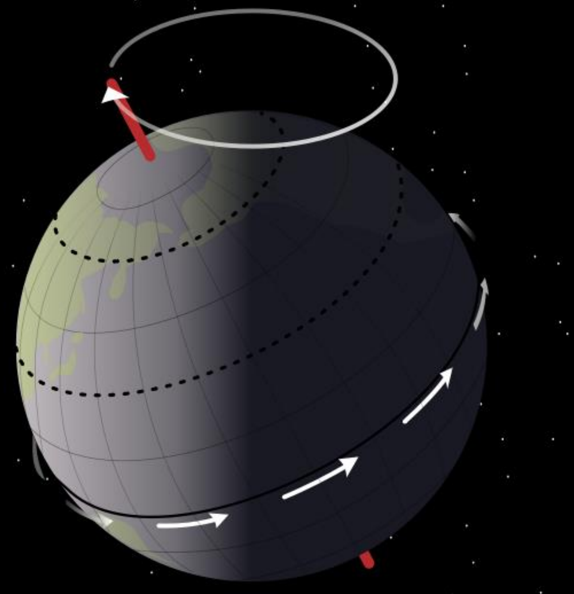


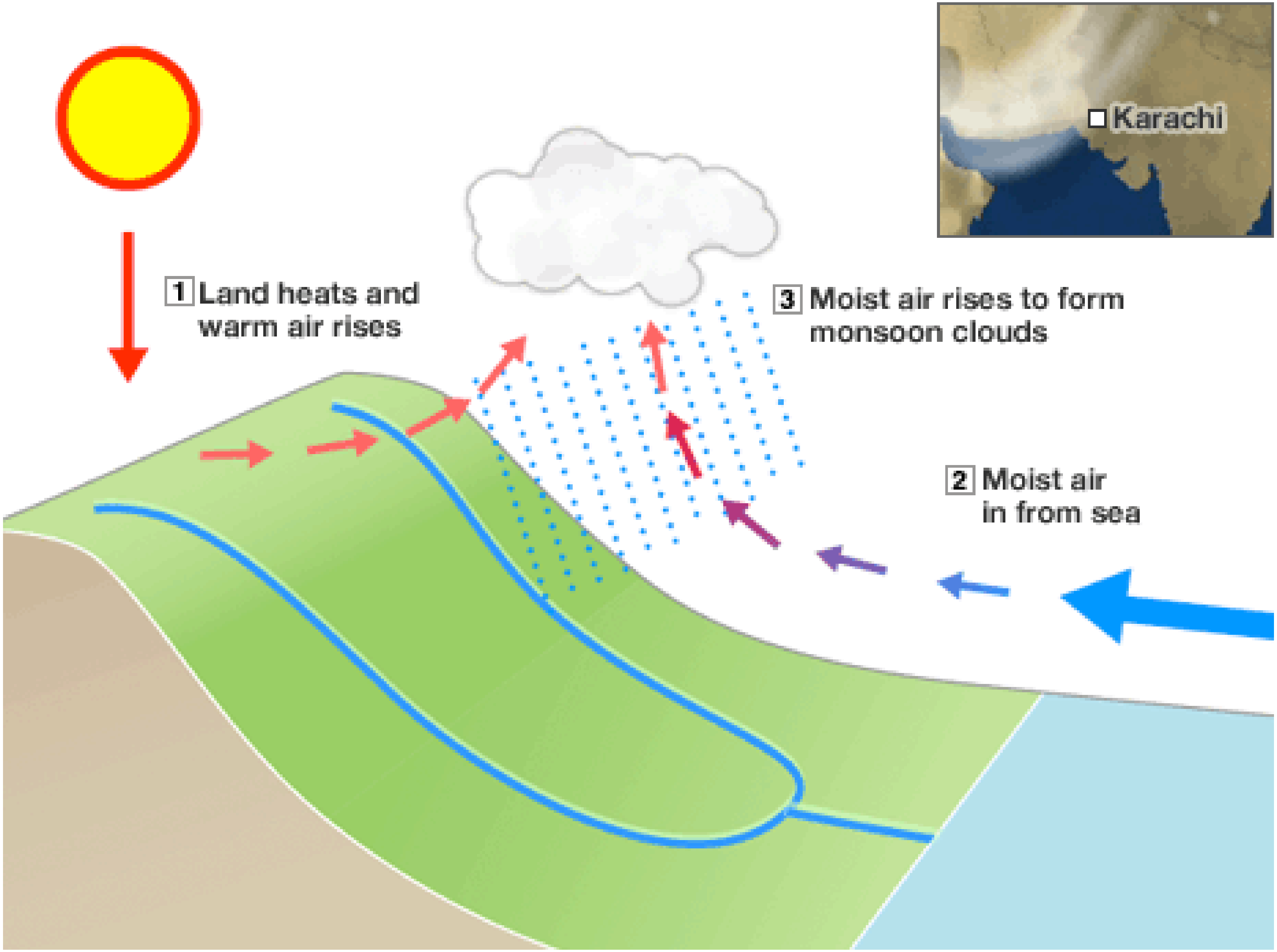
---- interactions ------

Resulting cycles @ 100,000 41,000 23,000 yr

At 9000 years B.P. obliquity was 24.23° (the modern value is 23.45°), perihelion was 30 July (the modern value is 3 January), and eccentricity was 0.0193 (the modern value is 0.0167); these factors combine to produce solar radiation differences for July that exceed 7 percent and 25 to 35 W/m^2 over a broad band of latitudes (6) (Table 1).

9000 yr BP: greater obliquity + summer-time perihelion

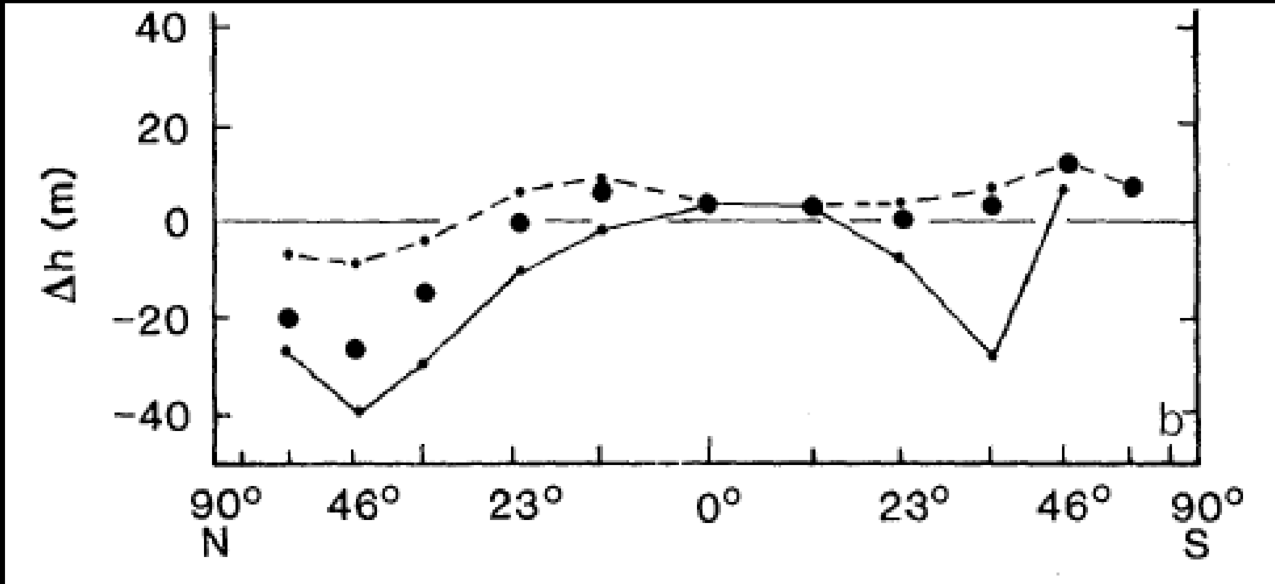




Karachi
1 Land heats and warm air rises
3 Moist air rises to form monsoon clouds
2 Moist air in from sea

Table 1. Latitudinal distribution of solar radiation for July 9000 years B.P. compared to modern values.

Latitude	Solar radiation (W/m^2)			Percent change
	9000 years B.P.	Modern	Difference	
81.1°N	522	486	36	7.4
69.6°N	496	462	34	7.5
58.0°N	498	464	34	7.3
46.4°N	513	478	35	7.3
34.8°N	516	481	35	7.2
23.2°N	504	470	34	7.2
11.6°N	474	443	31	7.2
0.0°	429	400	29	7.1



[redacted] Height differences Δh (9000 years B.P. minus the present): (●) over land and ocean, (solid line) over land, and (dashed line) over ocean. Negative differences indicate decreased height (lower pressure) at 9000 years B.P. compared to the present. Model standard deviations (based on independent modern simulations) are typically 5 to 10 m.

Over the African-Eurasian land mass both the low-level cyclonic inflow of air and the high-troposphere anticyclonic outflow of air are stronger at 9000 years B.P. than at present. At the surface, increased southwesterly winds carry moisture into West Africa and India.

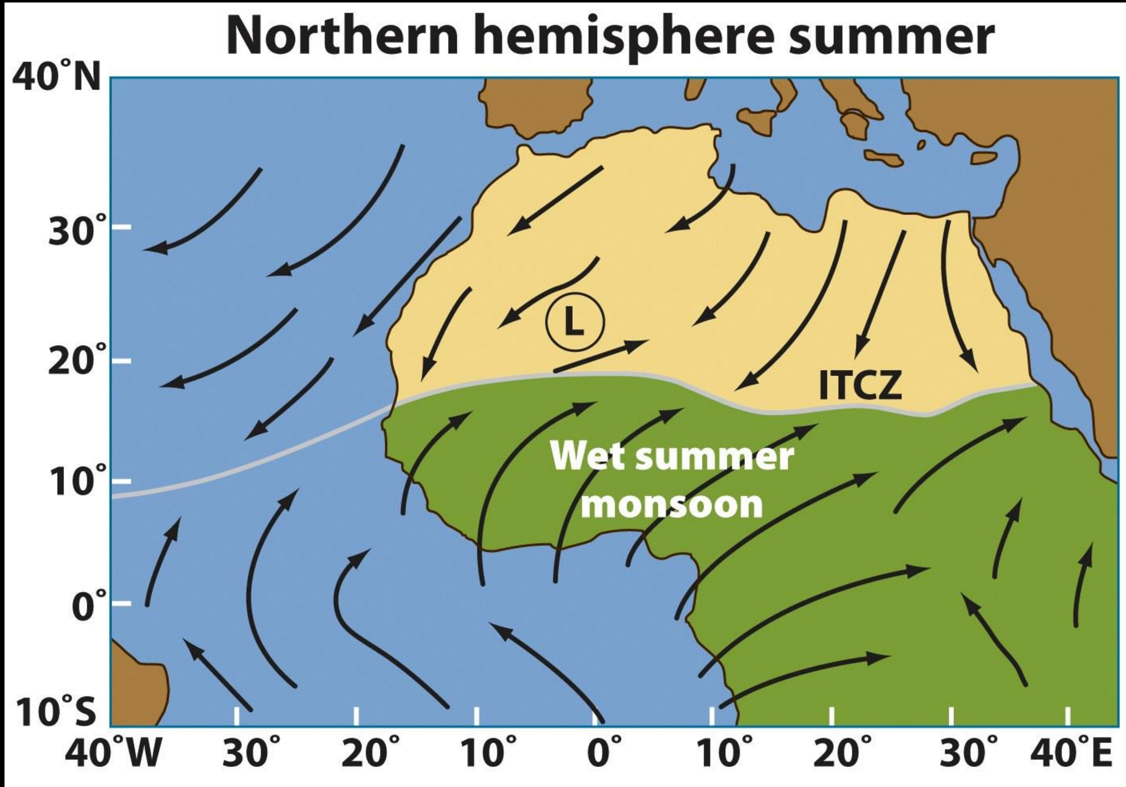


Table 2. Simulated surface temperature and precipitation for June to August averages and annual averages for Northern Hemisphere land, Southern Hemisphere land, and the global average of land and ocean for 9000 years B.P. compared to modern values. The difference between 9000 years B.P. and the present is denoted by Δ. The significance level (S.L.) is determined from the ratio of Δ to the model standard deviation.

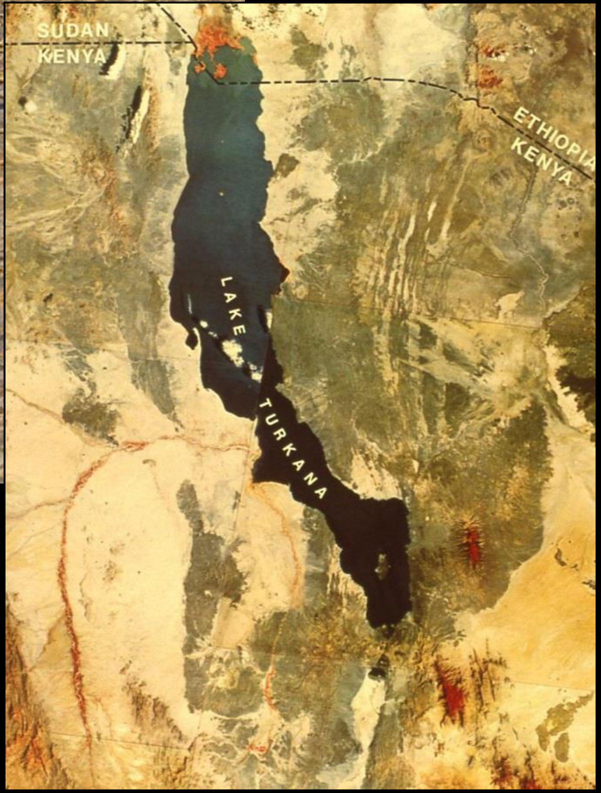
Space average	Surface temperature			S.L. (%)	Precipitation (cm/day)			S.L. (%)
	9000 years B.P. (°C)	Modern (°C)	Δ (K)		9000 years B.P.	Modern	Δ	
	June to August							
Northern Hemisphere, land	24.5	23.8	0.7	1	0.45	0.41	0.04	5
Southern Hemisphere, land	2.0	1.7	0.3		0.47	0.45	0.02	
Global, land and ocean	17.7	17.5	0.2	5	0.35	0.35	0	

CHAPTER 8

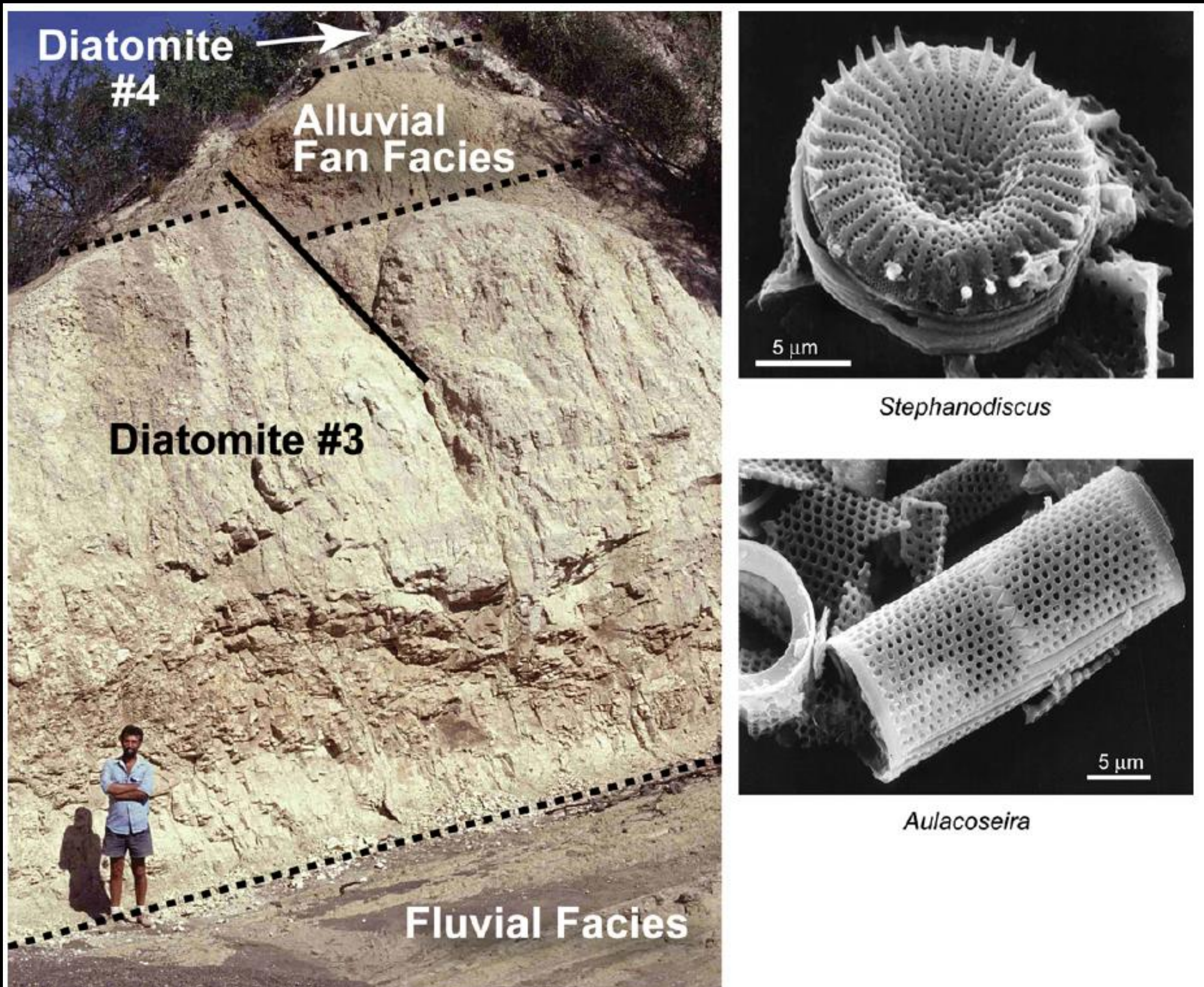
Insolation Control of Monsoons

Ruddiman uses correlations between monsoon history and orbital variations to illustrate their powerful role in Earth's climate.

What's the geological evidence?



Lake Turkana (Rudolf)

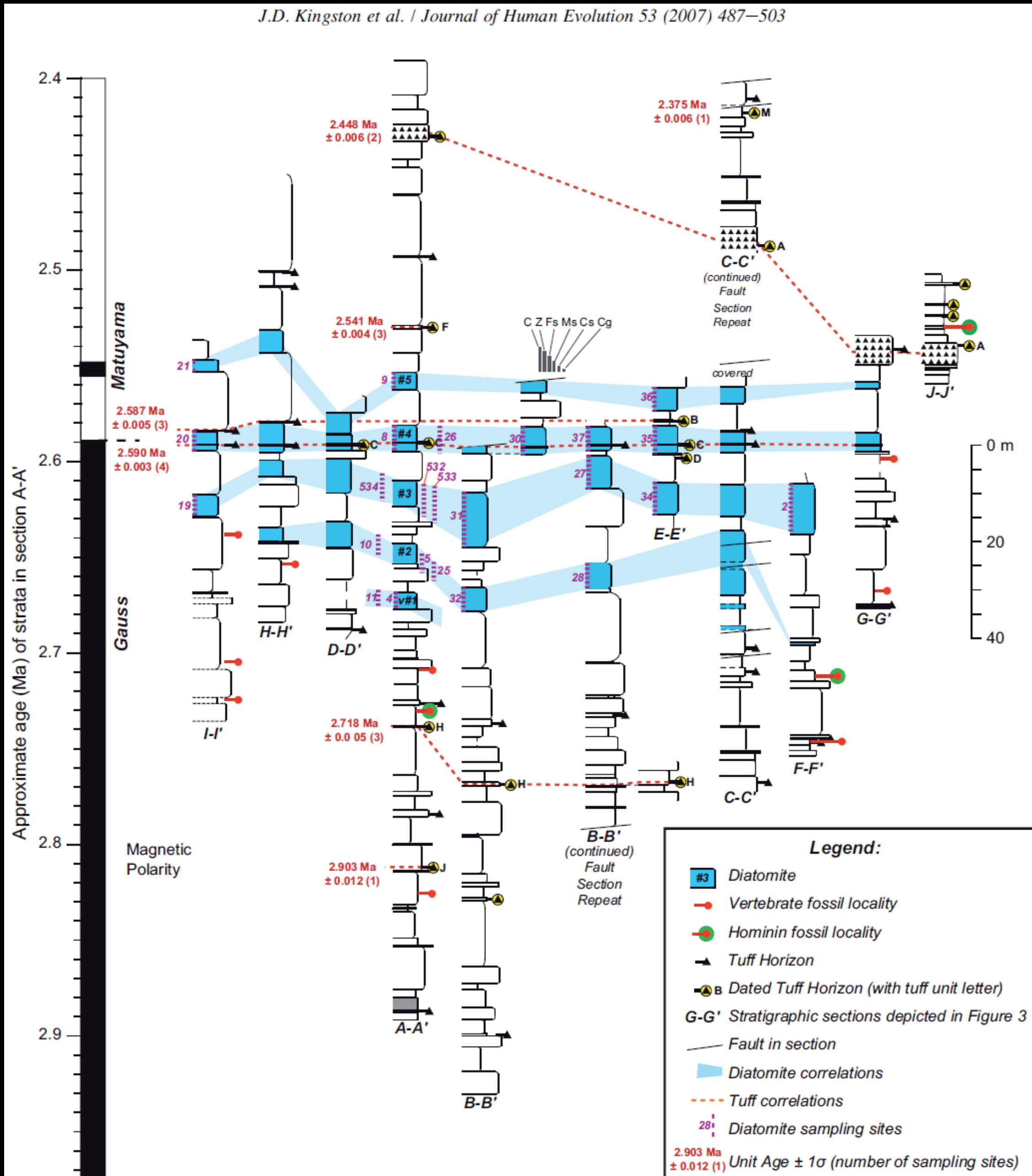


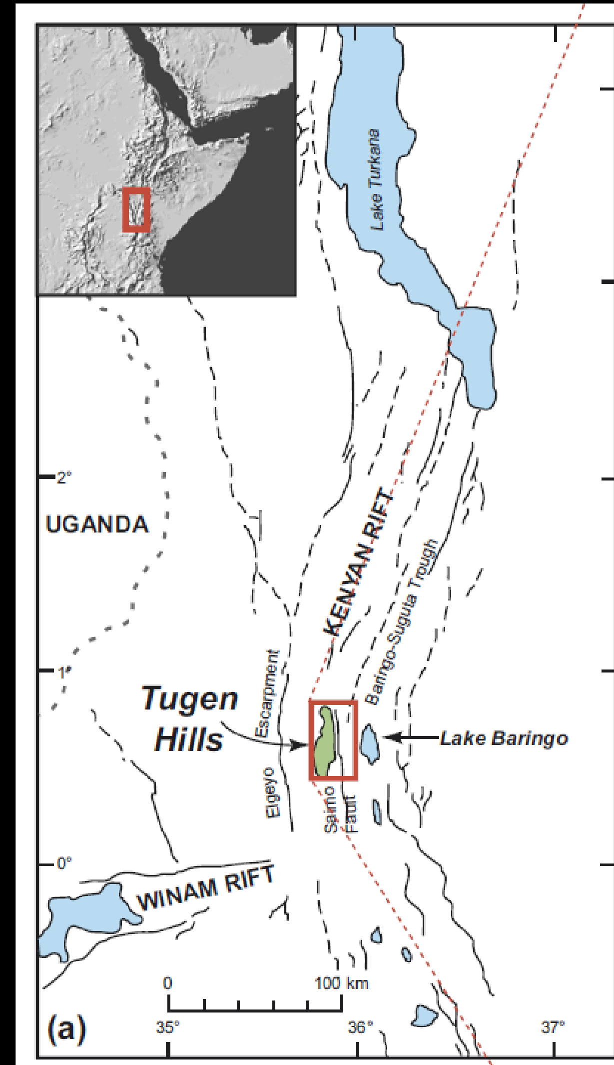
Astronomically forced climate change in the Kenyan Rift Valley 2.7−2.55 Ma: implications for the evolution of early hominin ecosystems

John D. Kingston [a,*], Alan L. Deino [b], Robert K. Edgar [c], Andrew Hill [d]

J of Human Evolution 2007

Fragmentary record from early Pleistocene



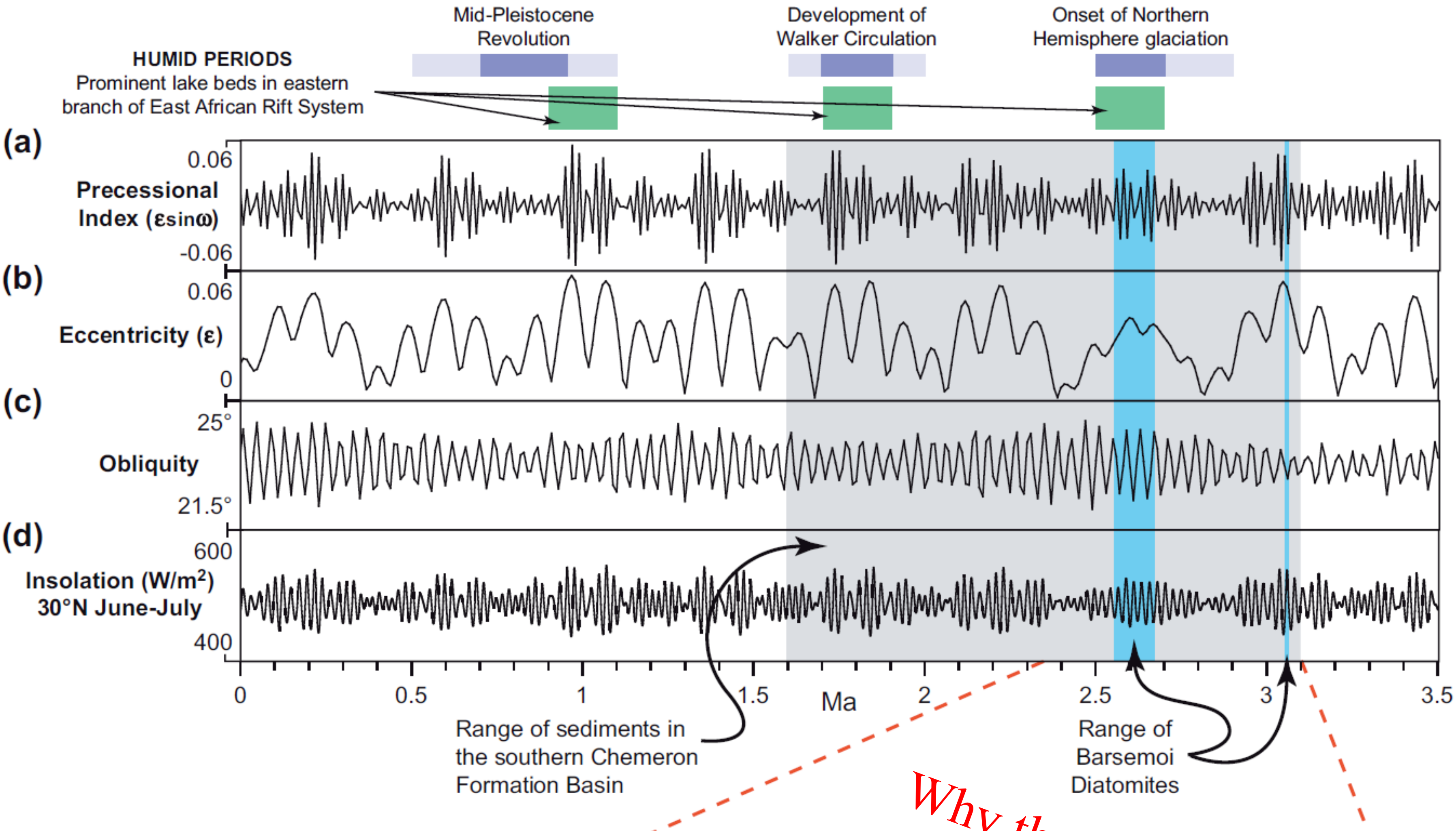


Lots of tectonism

Age control:

$^{40}Ar/^{39}Ar$ ages analyses from eight primary, anorthoclase-bearing tephra units from stratigraphic sections measured in the Barsemoi Tributary and adjacent drainages (Fig. 4;

Regional pluvials intermittently coincide with precessional radiation highs

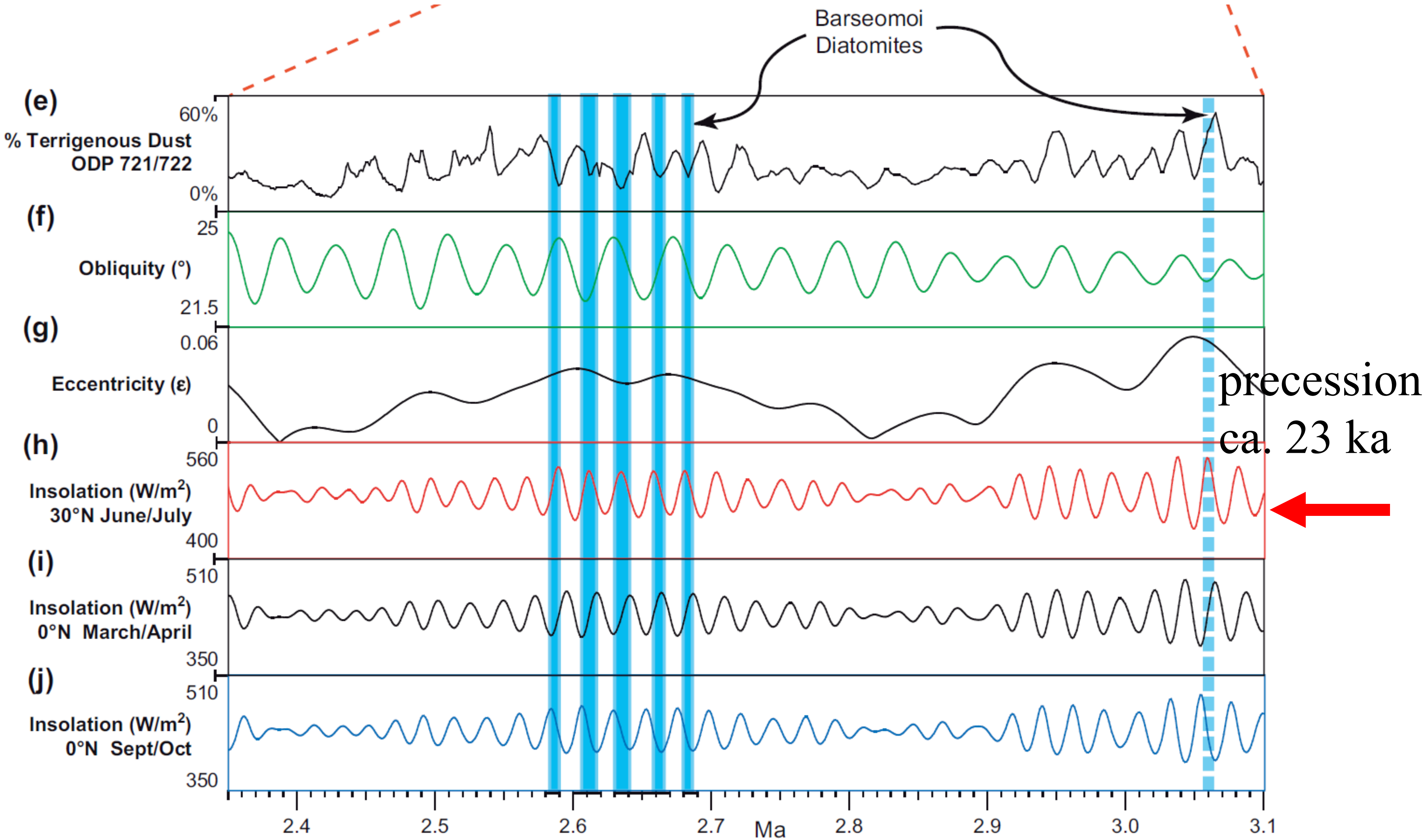


Astronomically forced climate change in the Kenyan Rift Valley 2.7–2.55 Ma: implications for the evolution of early hominin ecosystems

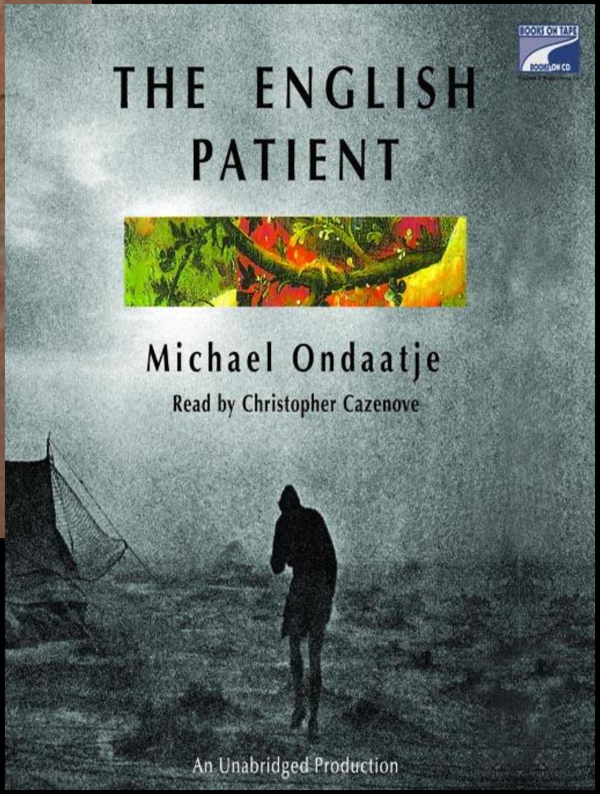
John D. Kingston [a,*], Alan L. Deino [b], Robert K. Edgar [c], Andrew Hill [d]

J of Human Evolution 2007

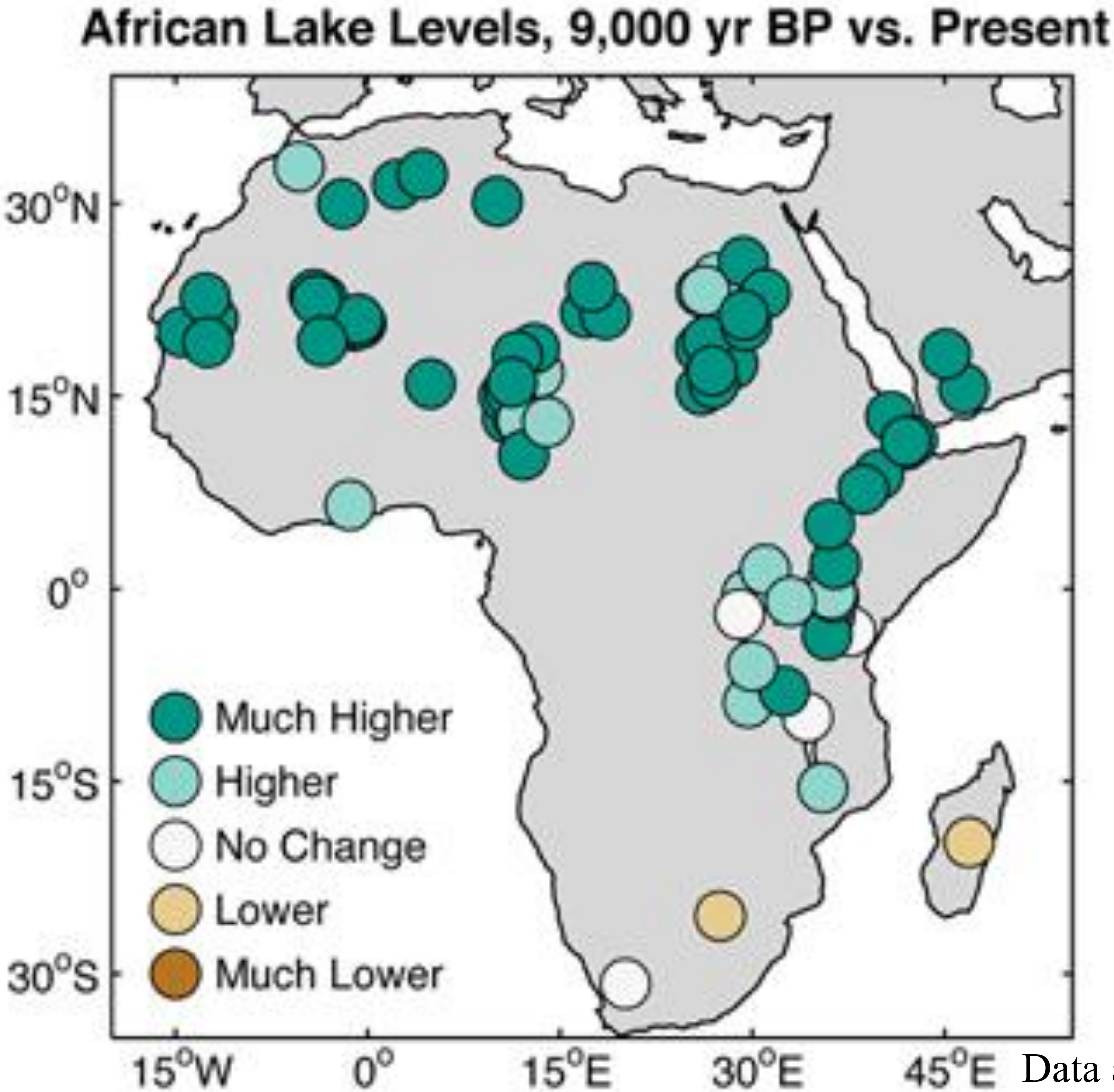
Detailed part of record shows pluvials coincided with precession cycle ca. 23 ka



More recent geological evidence for Milankovitch effects on monsoons



Gilf Kebir today



Today, perihelion occurs in northern hemisphere winter but at 10,000 years ago (half of a precession cycle) it occurred in northern hemisphere summer, and summer radiation over North Africa was about 7% higher than it is today (Berger, 1988; Kutzbach, 1981)

Data are from the Oxford Lake Level Database (COHMAP members, 1988, Street-Perrott *et al.*, 1989) updated with lake-level reconstructions generated in the last twenty years (Tierney *et al.*, 2011).

Green Sahara: African Humid Periods Paced by Earth's Orbital Changes

By: Peter B. deMenocal & Jessica E. Tierney © 2012 Nature Education

Citation: deMenocal, P. B. & Tierney, J. E. (2012) Green Sahara: African Humid Periods Paced by Earth's Orbital Changes. Nature Education Knowledge 3(10):12

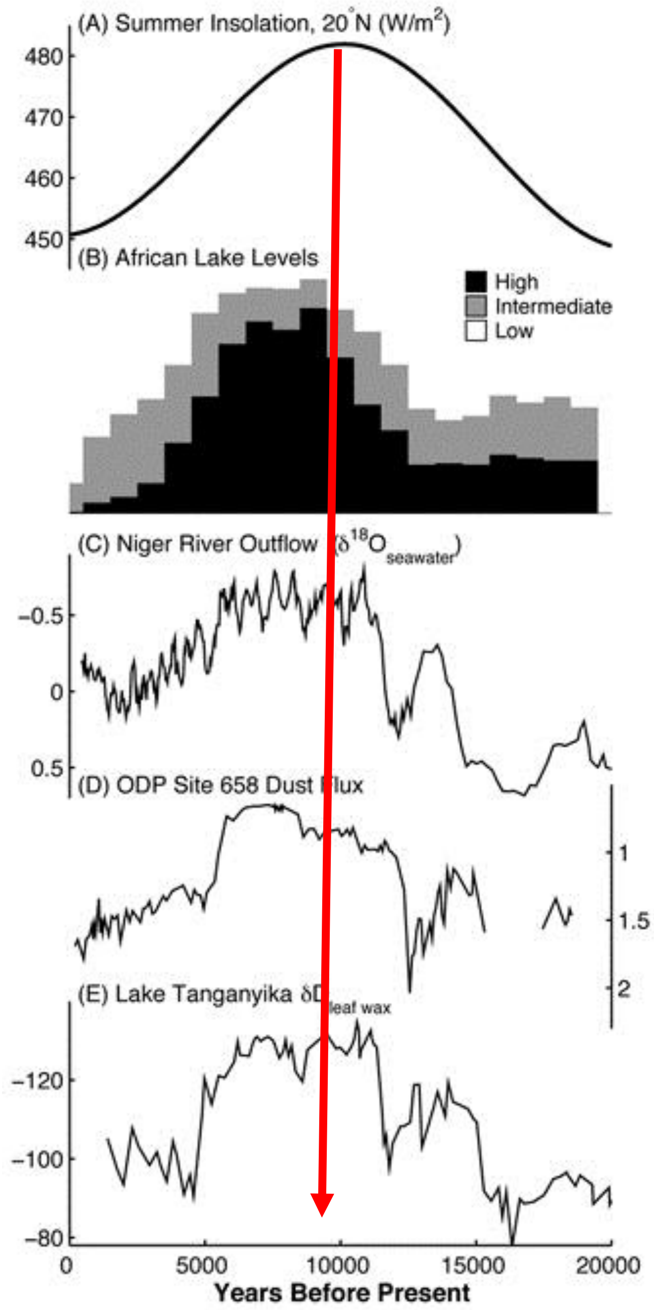


Figure 2

(a) Change in seasonal (summer) insolation for North Africa (20˚N) and paleoclimate records of the African Humid Period: (b) African lake level status (updated Oxford Lake Level Database; COHMAP members, 1988, Street-Perrott *et al*., 1989, Tierney *et al*., 2011), (c) Niger River outflow inferred from $\delta^{18}O_{seawater}$, (Weldeab *et al*., 2005); (d) Ocean Drilling Program (ODP) Site 658 dust flux (deMenocal *et al*., 2000, Adkins *et al*., 2006); (e) Lake Tanganyika δD of leaf waxes (δD_{wax}; Tierney *et al*., 2008).

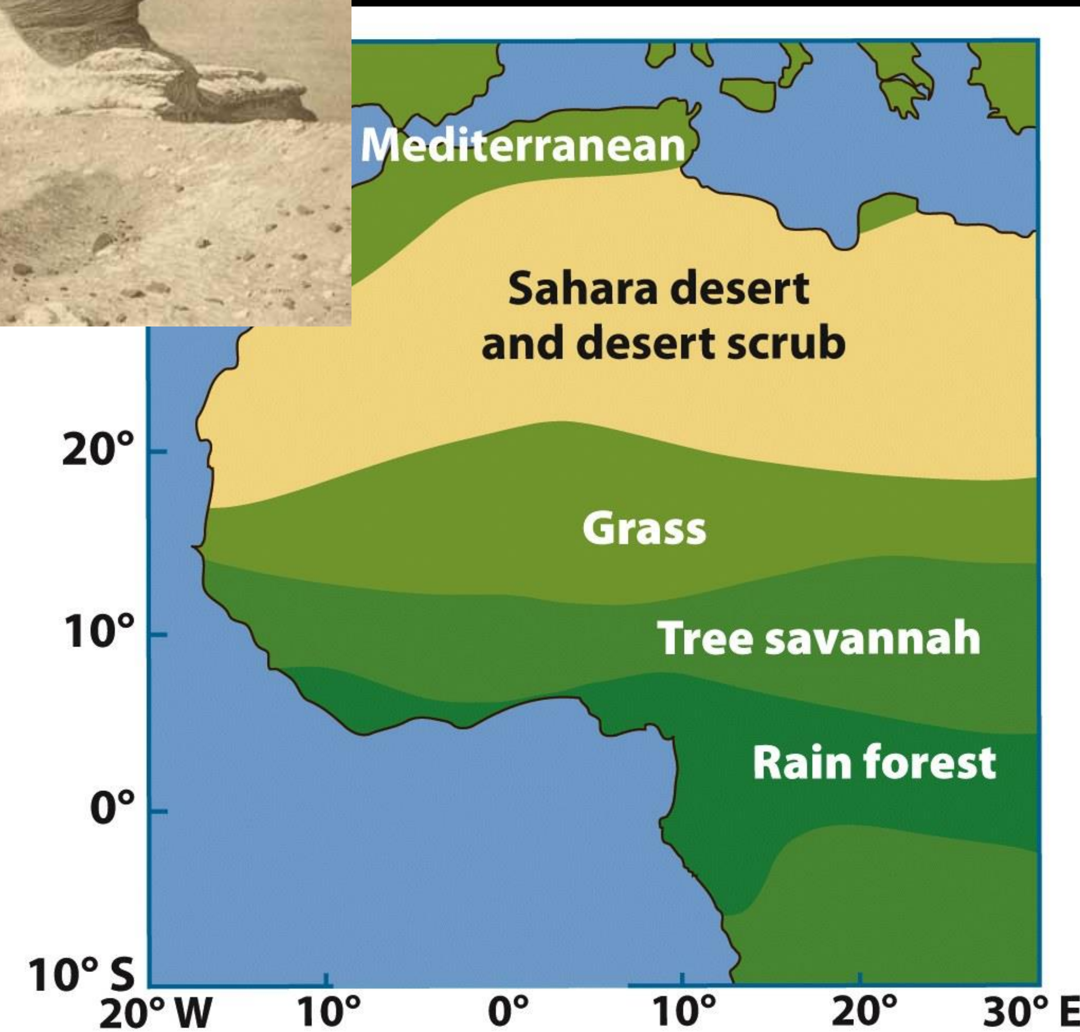


Figure 8-3 part 1
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The Nile drains regions dominated by monsoonal rainfall

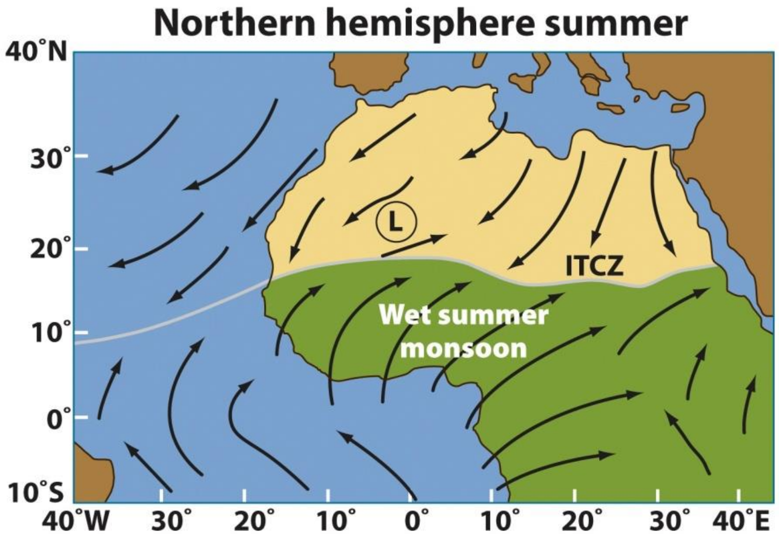
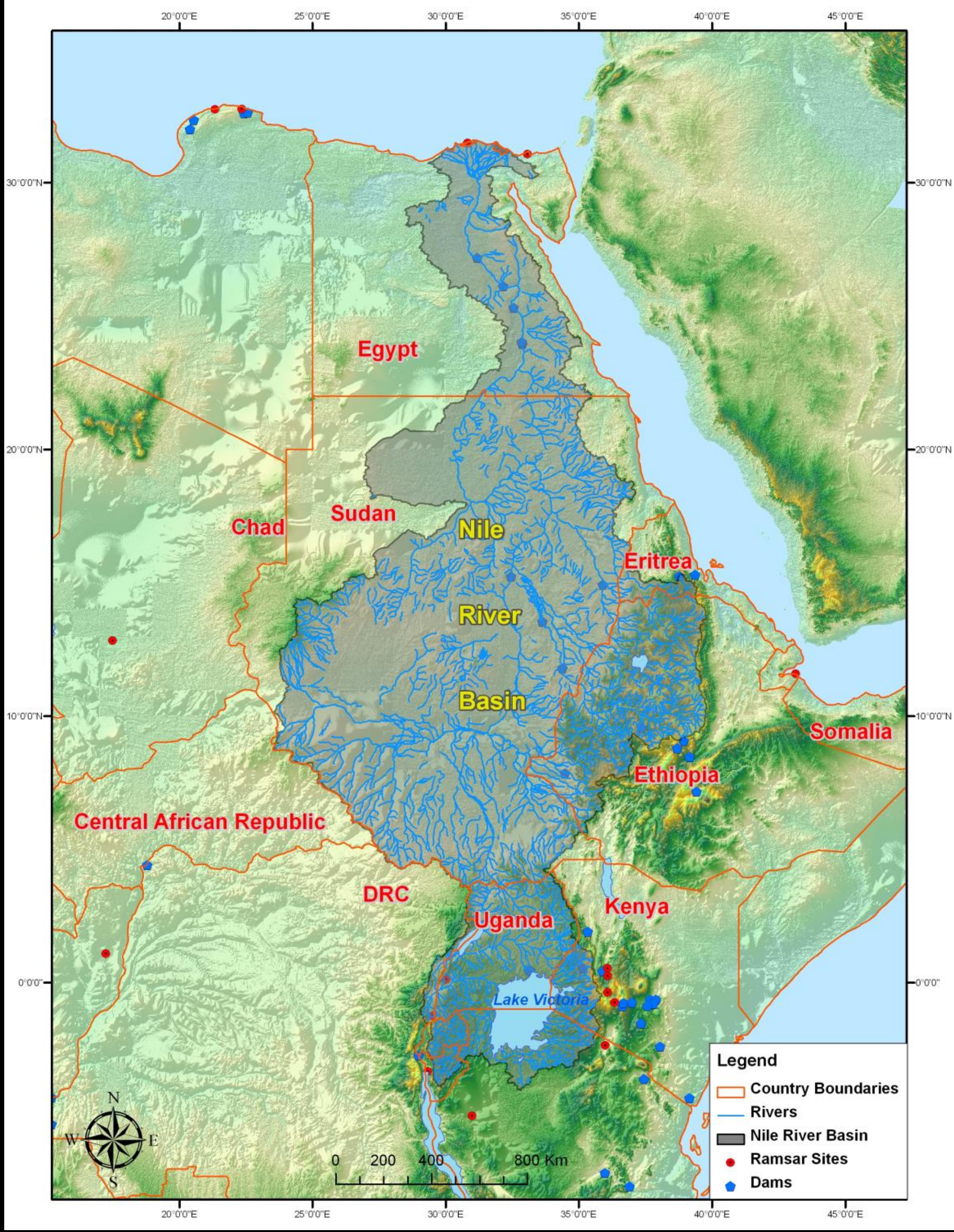


Figure 8-2a
Earth's Climate: Past and Future, Second Edition



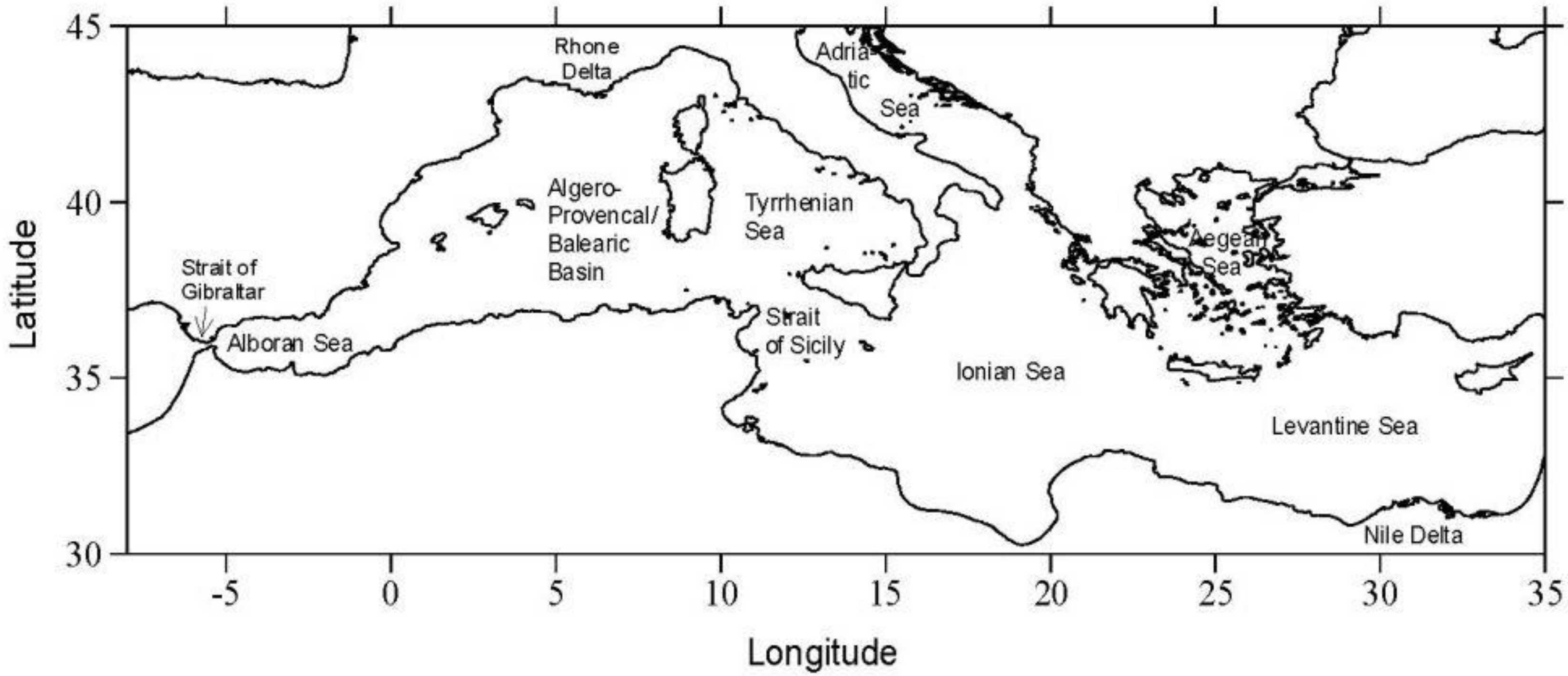
Sapropel (a contraction of ancient Greek words *sapros* and *pelos*, meaning putrefaction and mud, respectively) is a term used in marine geology to describe dark-coloured sediments that are rich in organic matter.

Ptolemais, Cyrenaica

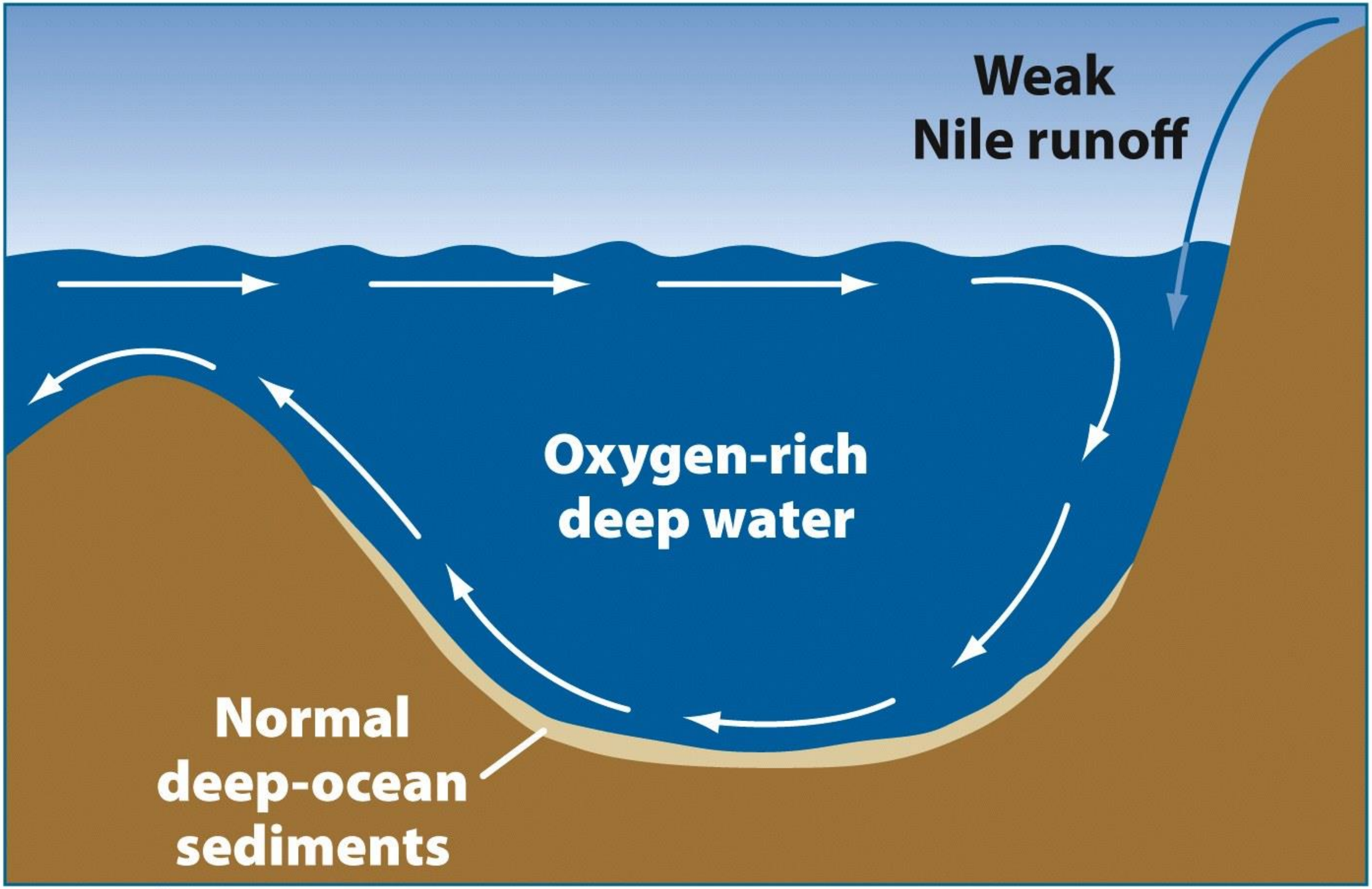
8-9 my old, uplifted marine sediment, Sicily

Sapropels are dark-coloured shale-like sediments rich in organic matter (>2% organic C)

Depths greater than 300 m became anoxic ca. 9500 BP and remained so until ca. 6000 BP

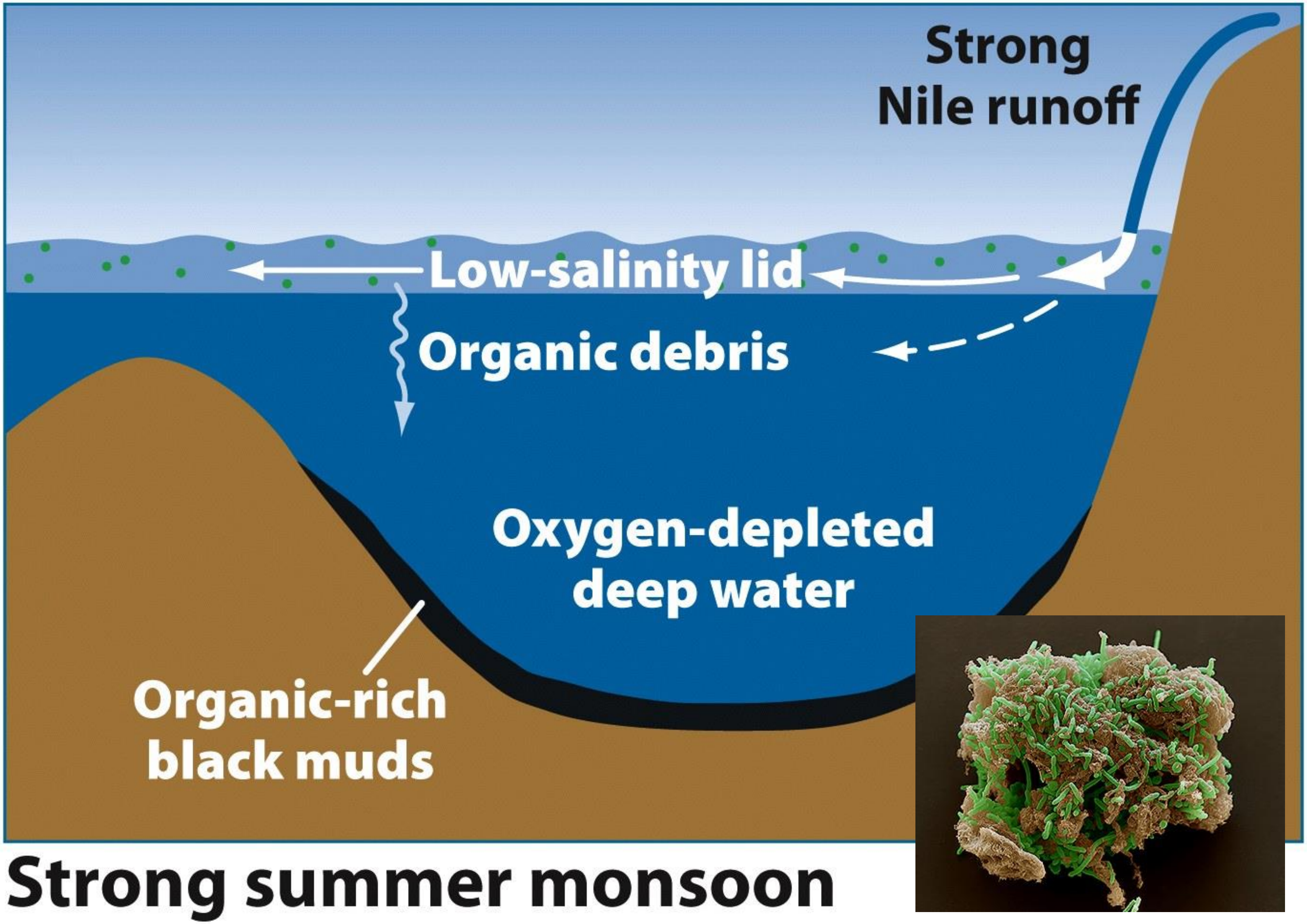


See interesting web page maintained by Eelco J. Rohling :www.noc.soton.ac.uk/soes/staff/ejr/DarkMed/dark-title.html



Weak summer monsoon

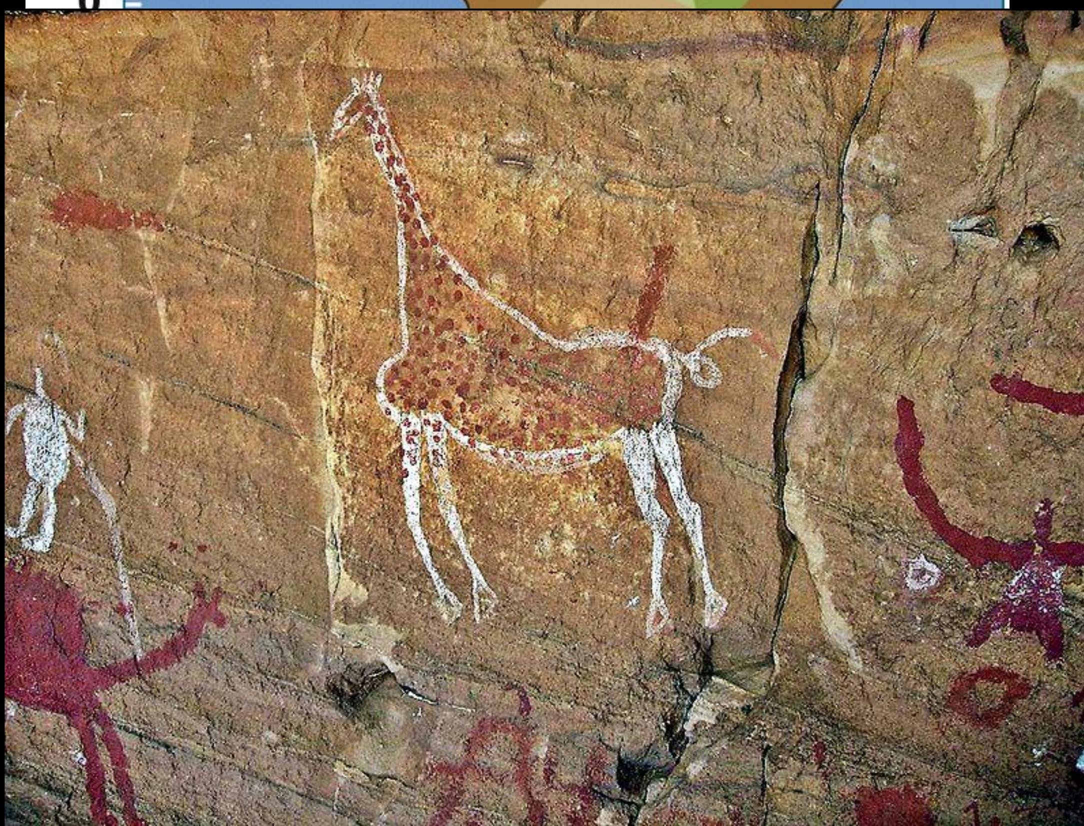
Figure 8-6a
Earth's Climate: Past and Future, Second Edition

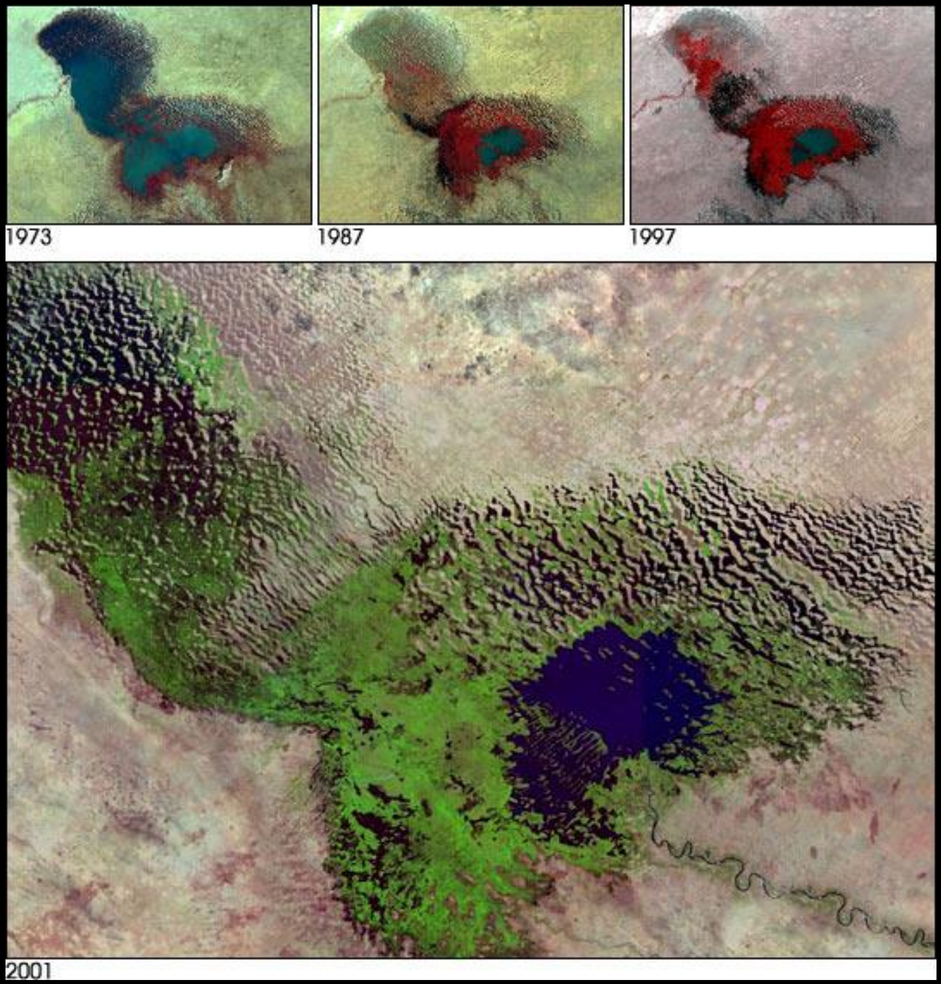


Strong summer monsoon

Figure 8-6b
Earth's Climate: Past and Future, Second Edition


40°N
30°
20°
10°
0°
Deposition
of sapropels
Nile
Stronger
monsoon





Why this is important….

Lake Chad today….

Journal Geophysical Research
2001
Coe and Foley:

"…30 percent decrease took place in the lake between 1966 and 1975. Irrigation only accounted for 5 percent of that decrease, with drier conditions accounting for the remainder. ..irrigation demands increased four-fold between 1983 and 1994, accounting for 50 percent of the additional decrease in the size of the lake. "

Nonlinearities in orbital forcing of monsoon rainfall in the Sahel

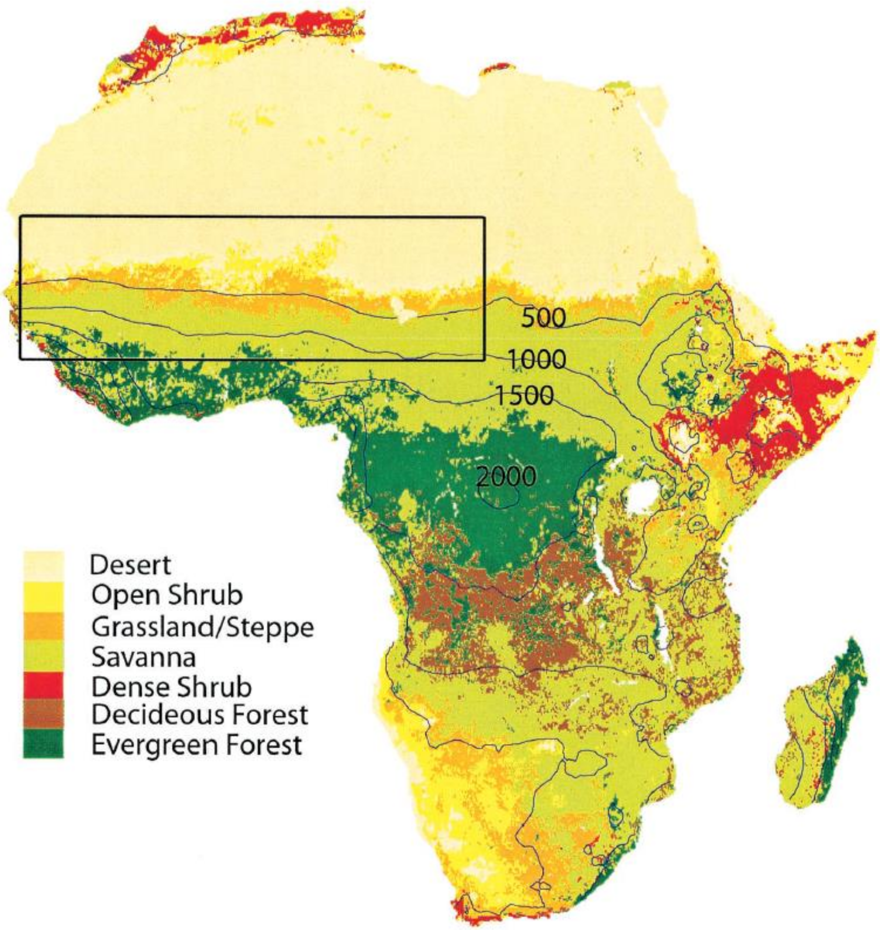
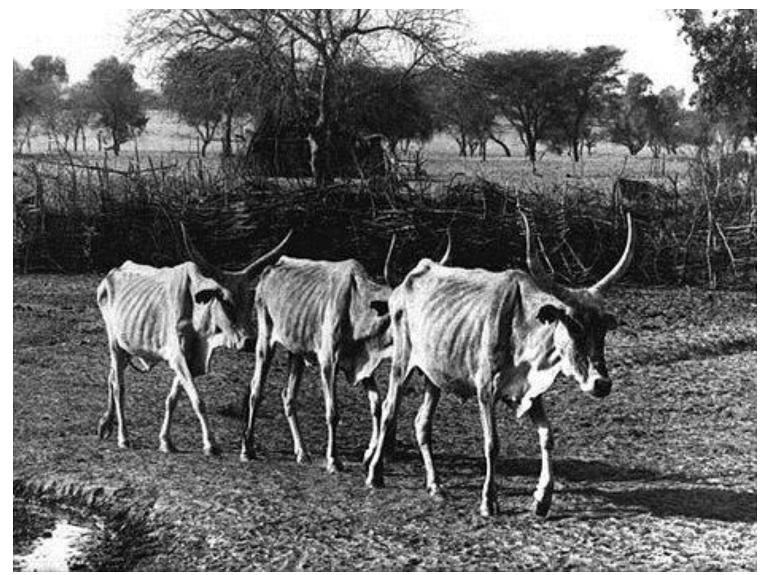


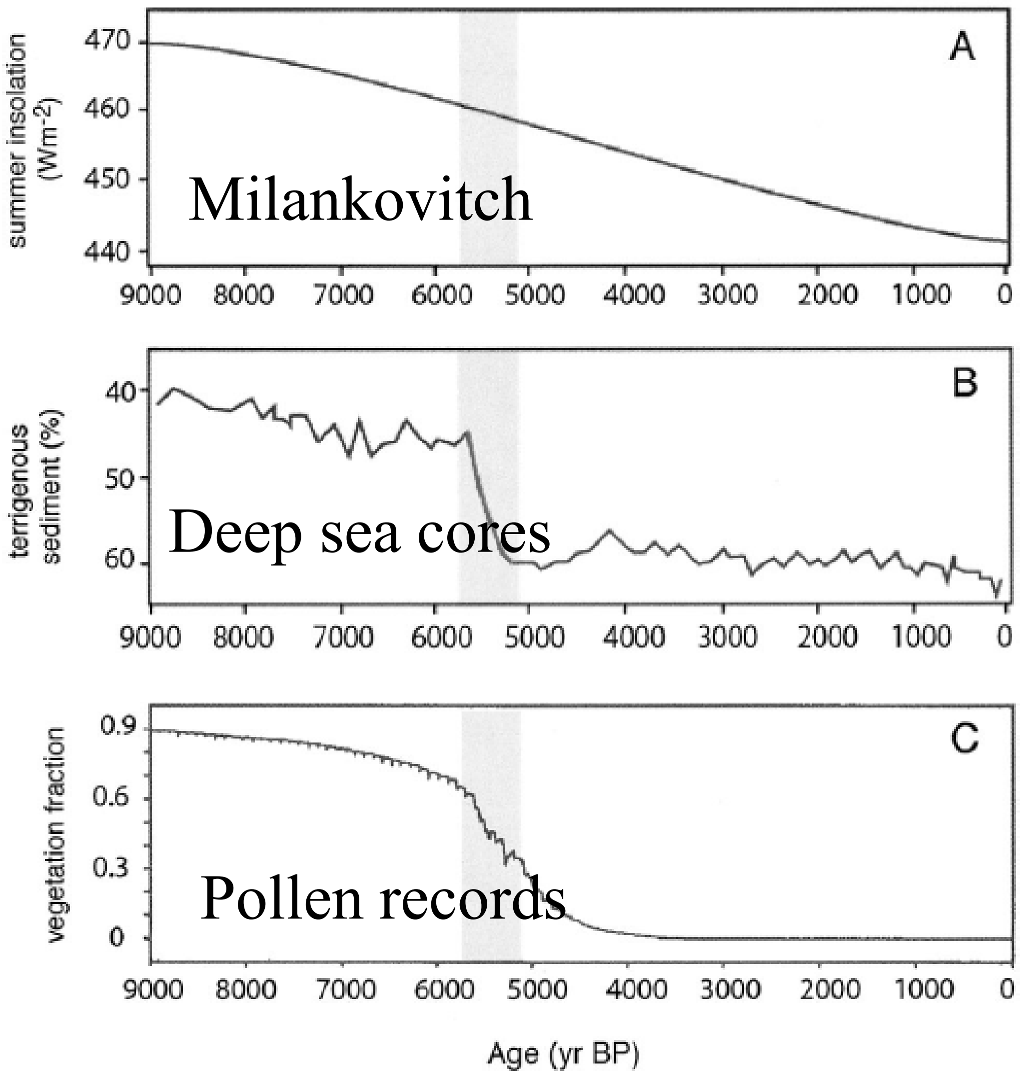
Figure 1. Vegetation cover and precipitation patterns of Africa. Patterns of precipitation (expressed as annual means, in units of mm/y) are tightly correlated with patterns of vegetation cover. Northern Africa is dominated by the Sahara, the largest hot desert on the planet today. The transition between the Sahara and the savannas to the south occurs in the Sahel zone (outlined in black).



Foley et al., Regime shifts in the Sahel, Ecosystems (2003)

Regime Shifts in Northern Africa 527

Foley et al (2003)

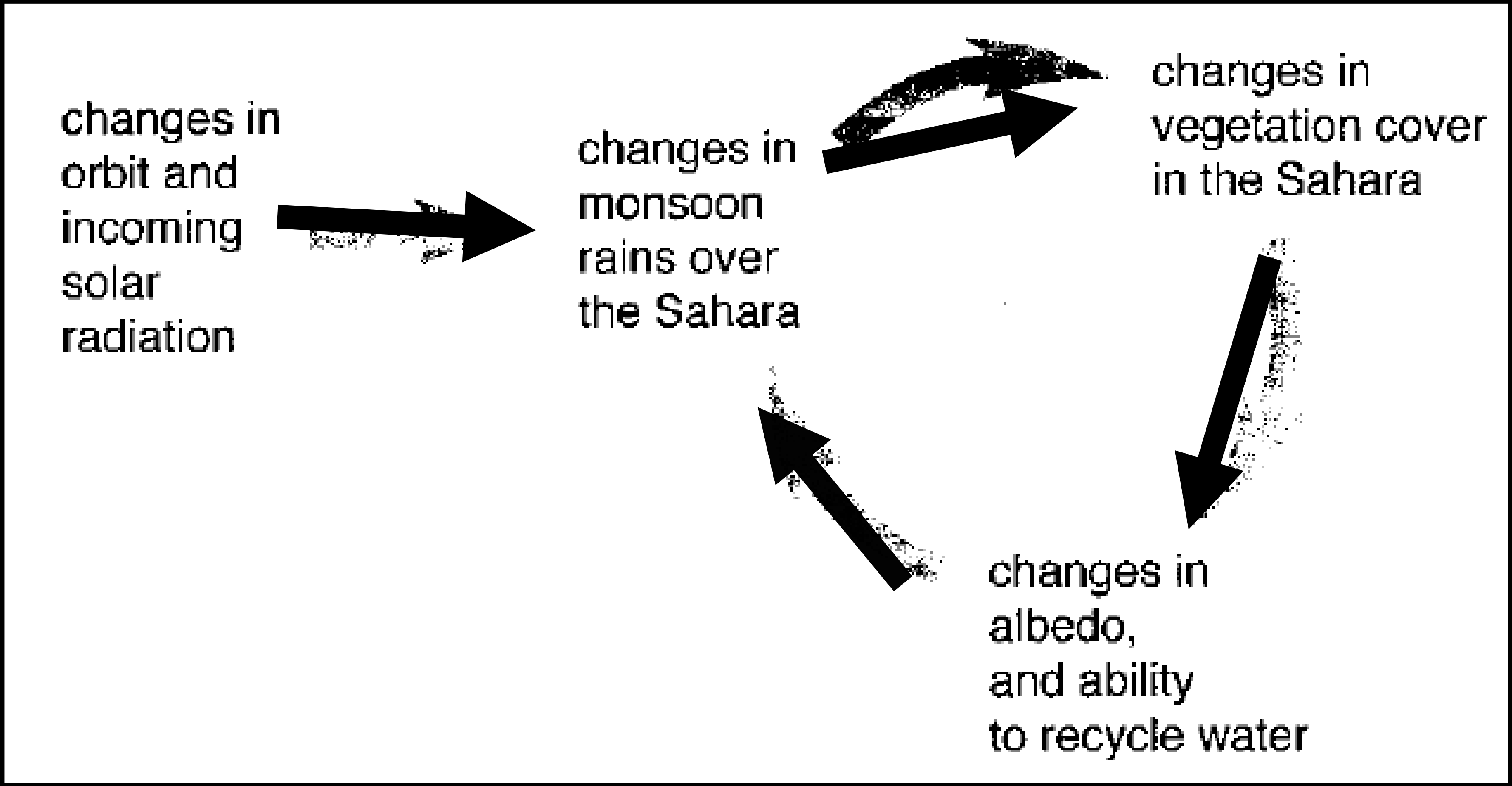


Slow orbital forcing

But sudden ecosystem responses

suggests presence of thresholds and feedbacks

Adapted from J. F. Griffiths, Climates of Africa [Amsterdam: Elsevier, 1972].



Foley et al (2003) Ecosystems.

Annual rainfall anomaly (mm)

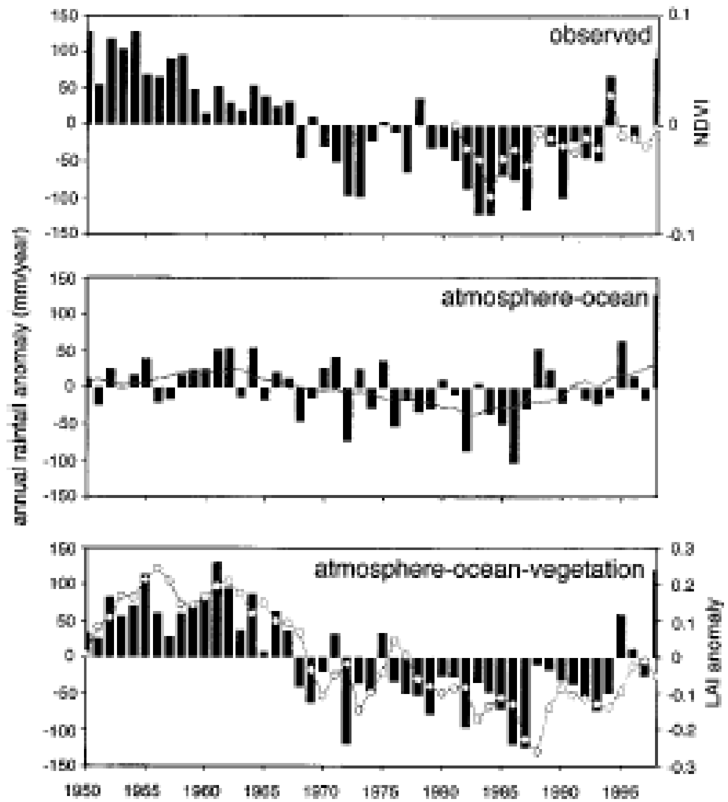


Figure 5. Observed and simulated precipitation histories over the Sahel. Zeng and others (1999) used a simplified coupled atmosphere–ocean–land model to investigate the mechanisms behind long-term climate variability in the Sahel region. They found that a model configured to represent only atmosphere–ocean coupling (B) did not match the observed record of precipitation (A). Only when vegetation dynamics and land-surface feedbacks were included in the model (C) did the model capture the long-term variations in rainfall observed in the Sahel. Figure redrawn from Zeng and others (1999)).

observed

modeled w/o veg. changes and feedbacks

veg. feedbacks included

Foley et al. (2003)

An additional complication….

orbital forcing from precession → monsoon rains

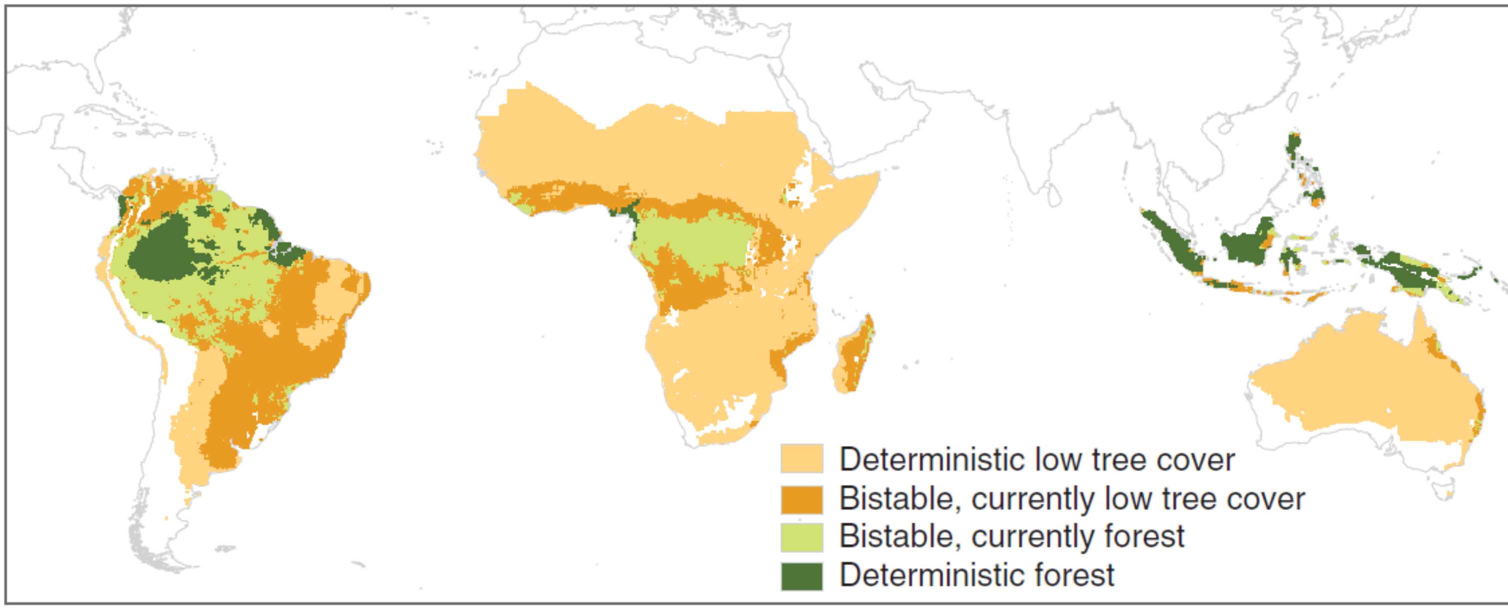
fire regime ⇄ vegetation/surface feedbacks

The Global Extent and Determinants of Savanna and Forest as Alternative Biome States

A. Carla Staver, *et al.*

Science **334**, 230 (2011);
DOI: 10.1126/science.1210465

Fig. 4. Distributions of biome types across sub-Saharan Africa, South America, and Southeast Asia/Australia. Biome types are defined as areas where climate (i) deterministically supports low tree cover (low rainfall, high seasonality); (ii) supports biome bistability (intermediate rainfall, mild seasonality), currently savanna; (iii) supports biome bistability, currently forest; and (iv) deterministically supports forest (high rainfall).



globally discontinuous. Climate influences tree cover globally but, at intermediate rainfall (1000 to 2500 millimeters) with mild seasonality (less than 7 months), tree cover is bimodal, and only fire differentiates between savanna and forest. These may be alternative states over large areas, including

To review…..Precession cycle brings several thousand years of increased summer radiation every 23 ka.

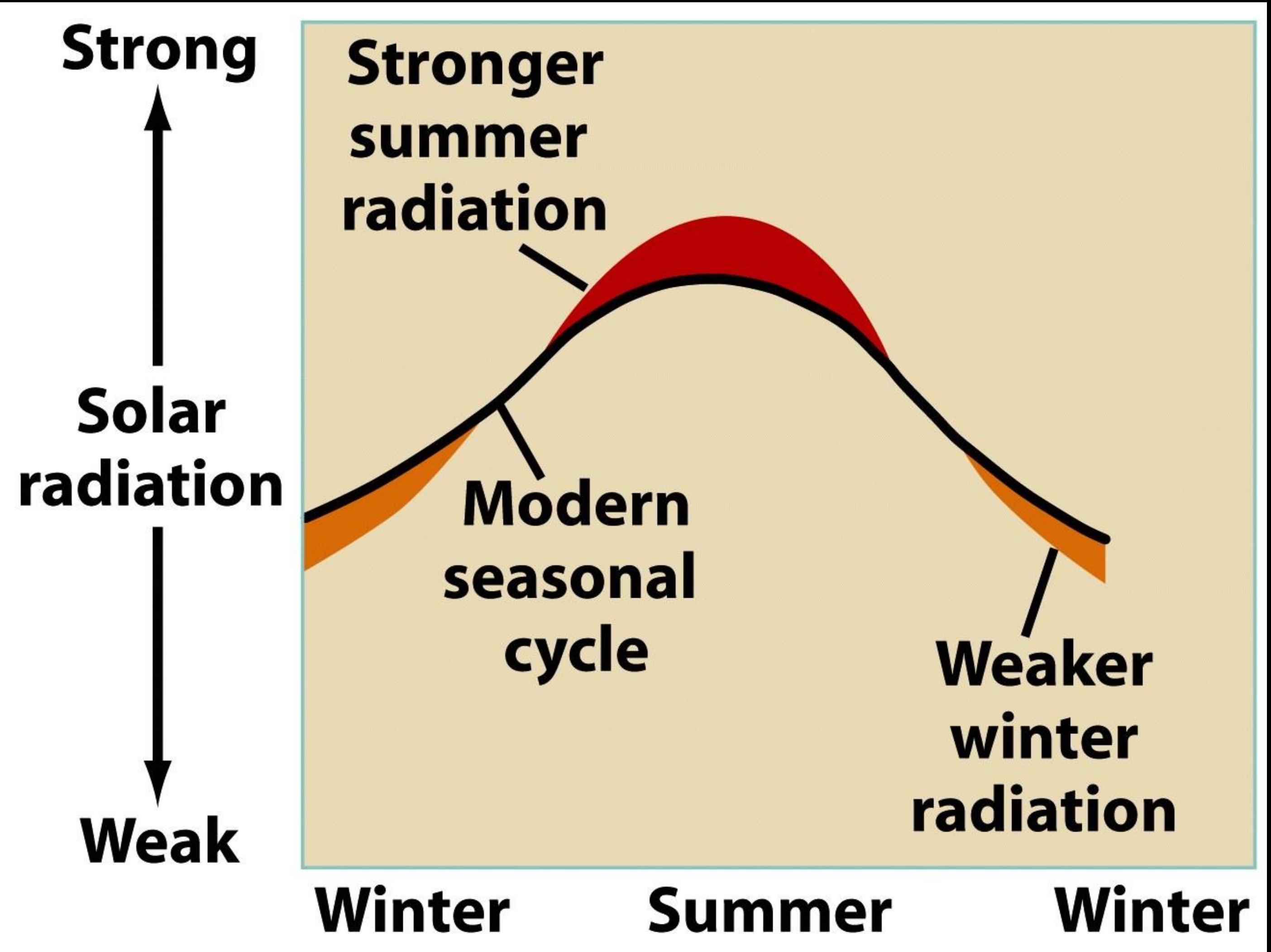


Figure 8-4a

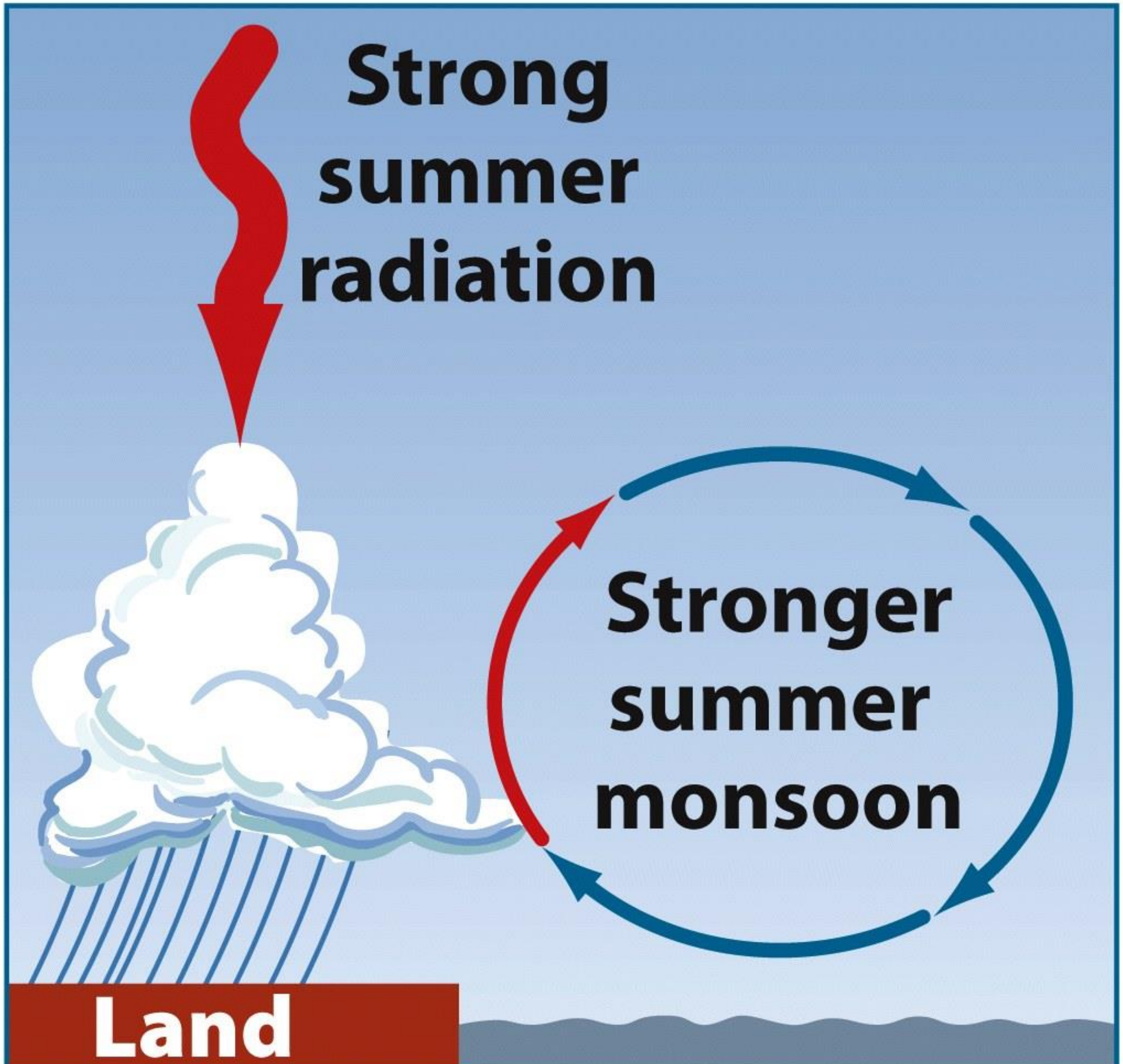


Figure 8-4b
Earth's Climate: Past and Future, Second Edition

rem: more intense summer insolation and weaker winter insolation ALWAYS occur together at one location

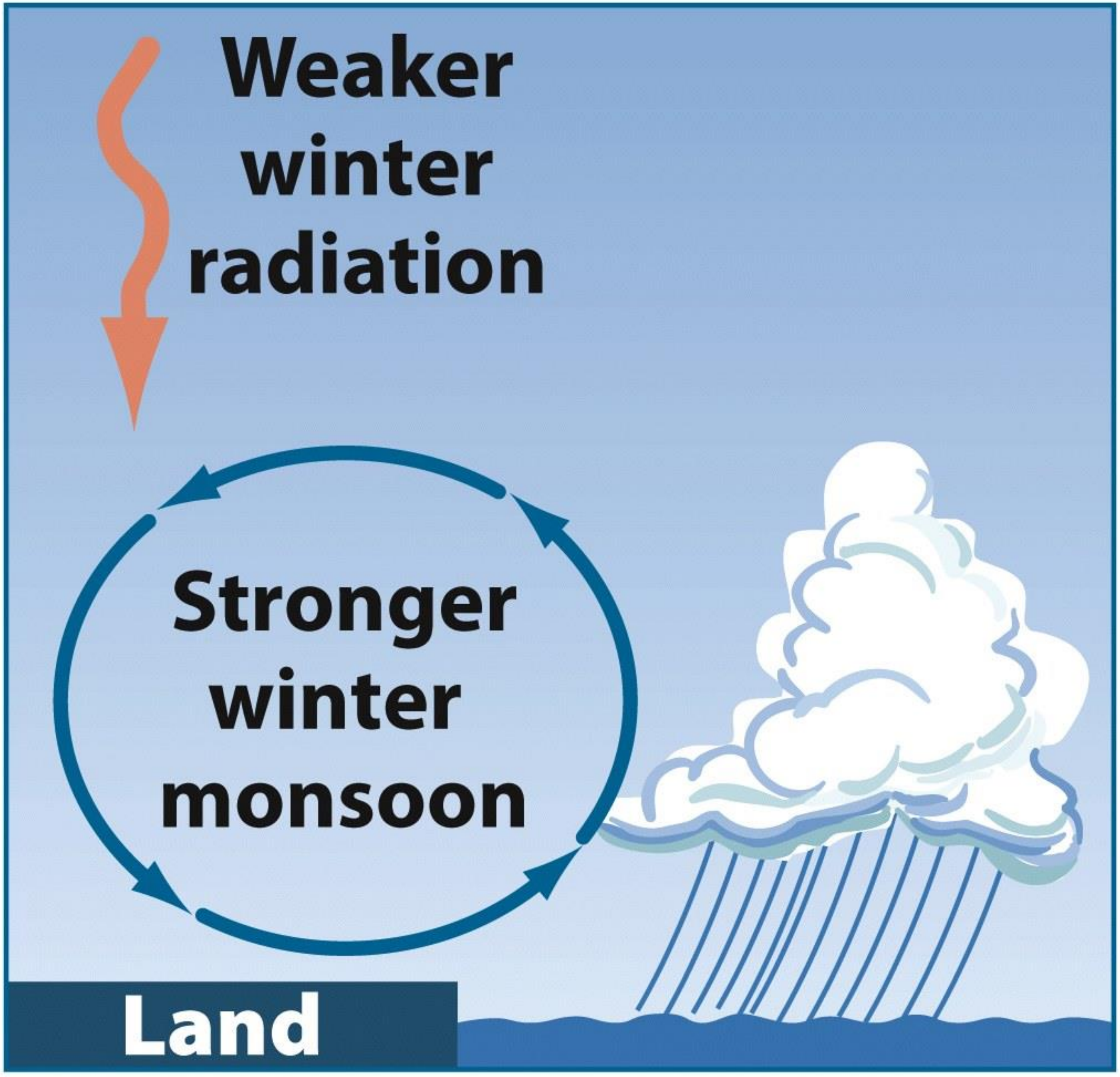


Figure 8-4c
Earth's Climate: Past and Future, Second Edition

changes in winter monsoon are irrelevant for moisture balance in the Sahel because winters are dry there anyway

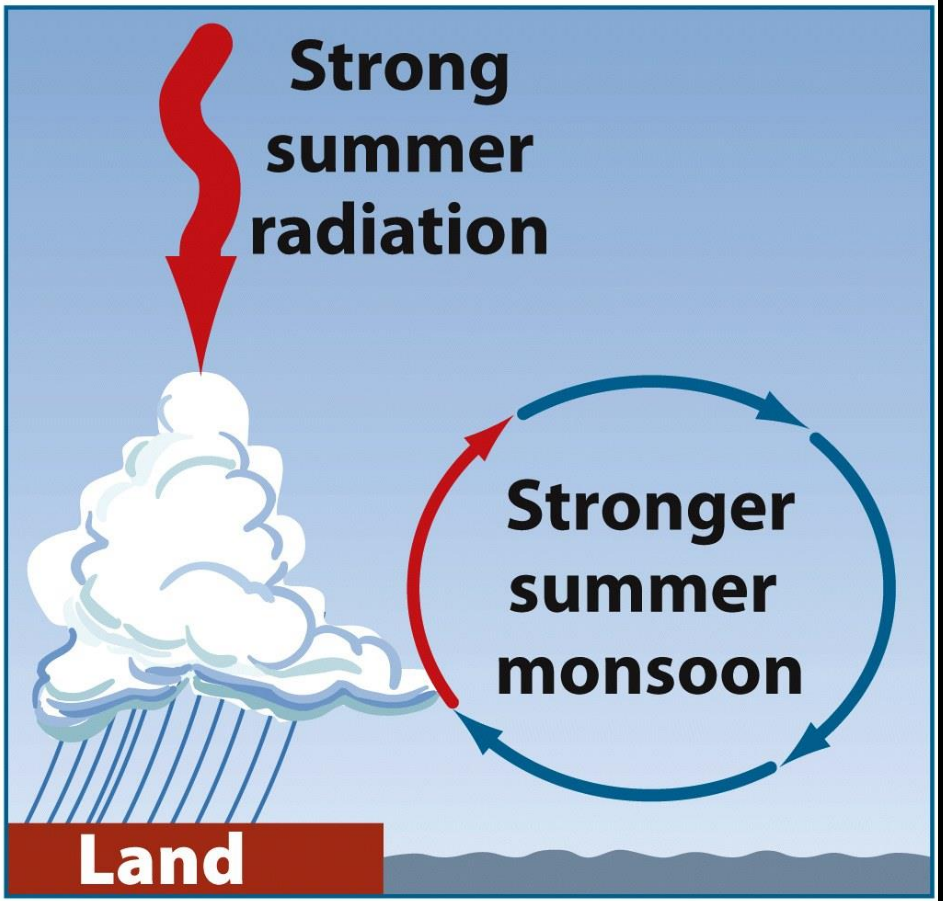


Figure 8-4b
Earth's Climate: Past and Future, Second Edition

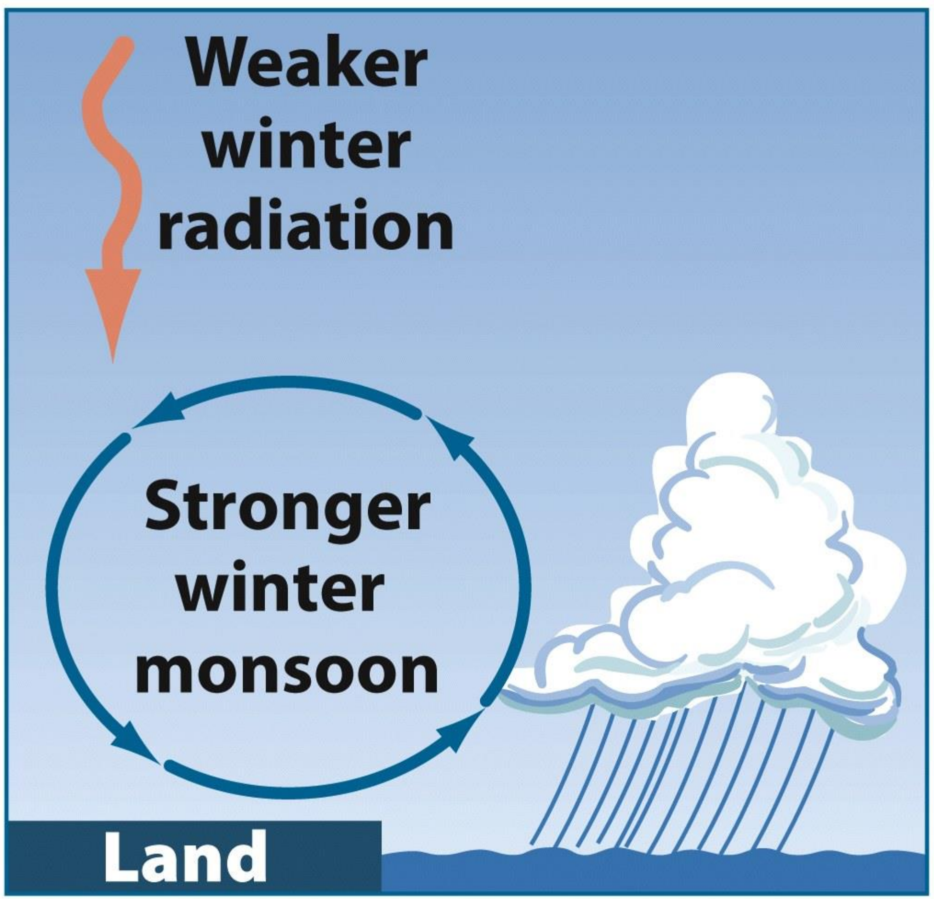


Figure 8-4c
Earth's Climate: Past and Future, Second Edition

Again, note the lack of any wintertime response

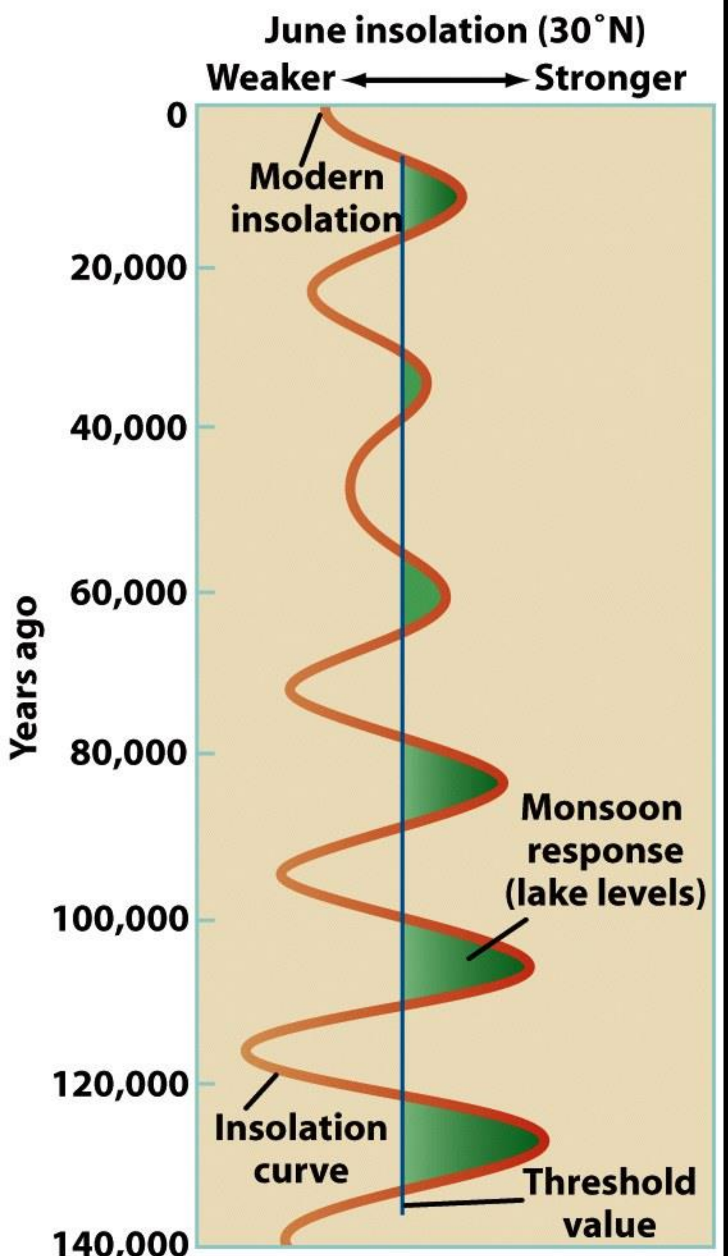
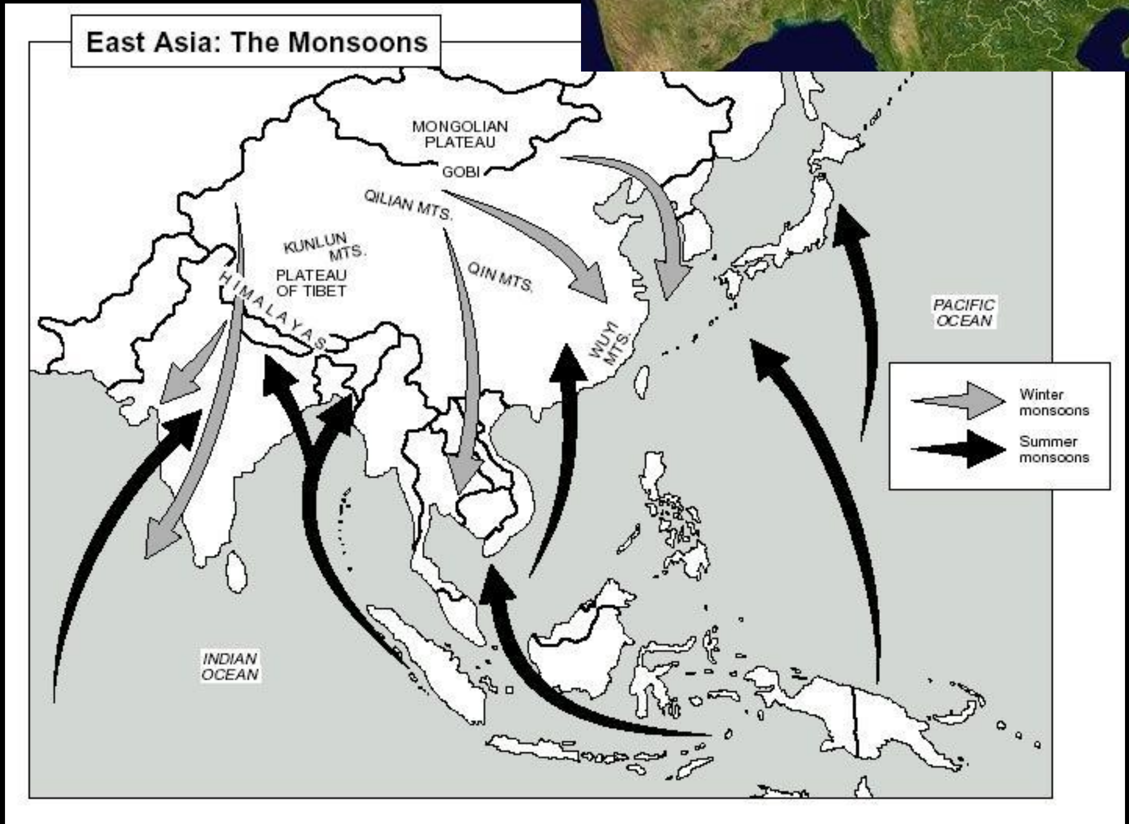


Figure 8-5
Earth's Climate: Past and Future, Second Edition

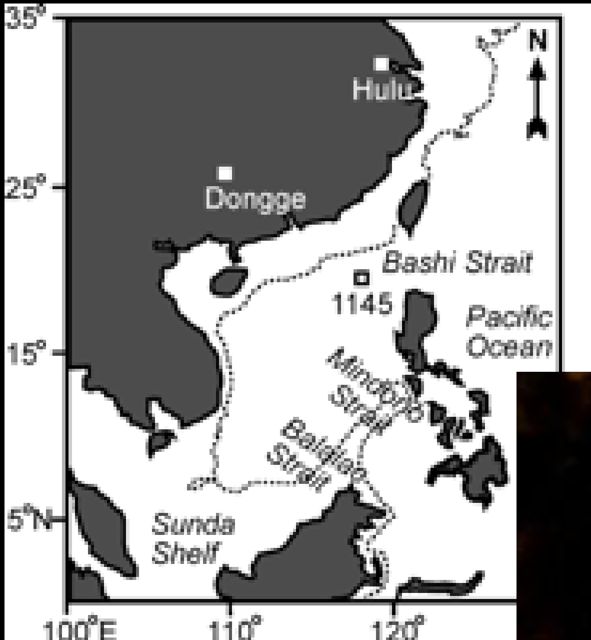
Ruddiman's summary of North African lake levels

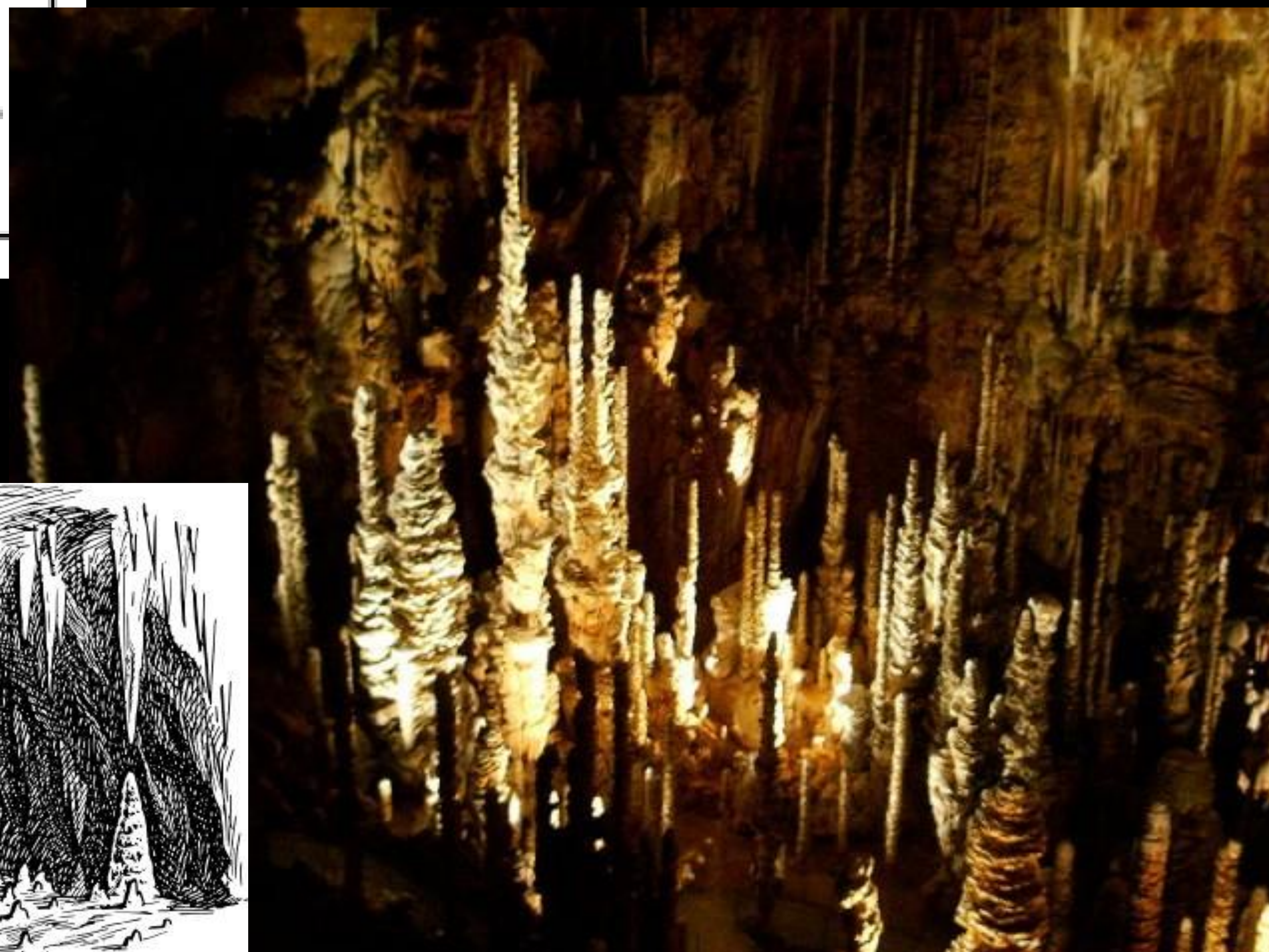
23,000-year precession of equinoxes shows up strongly in monsoons of other regions

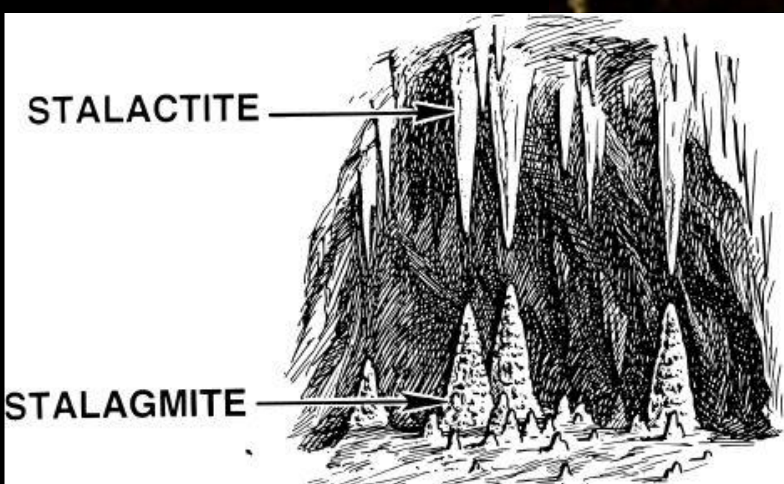


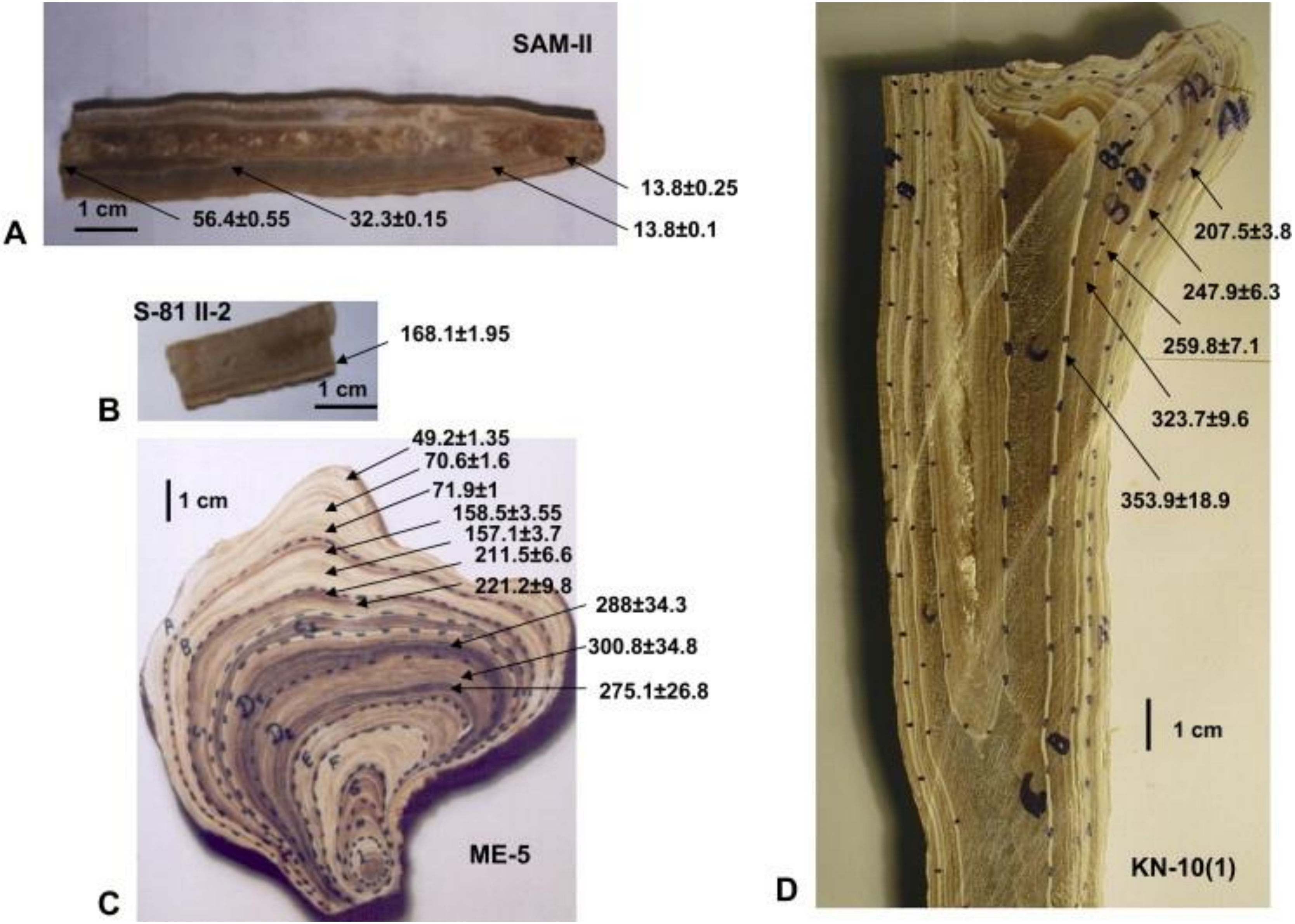
Fujian province, China

Hulu and Dongge Caves



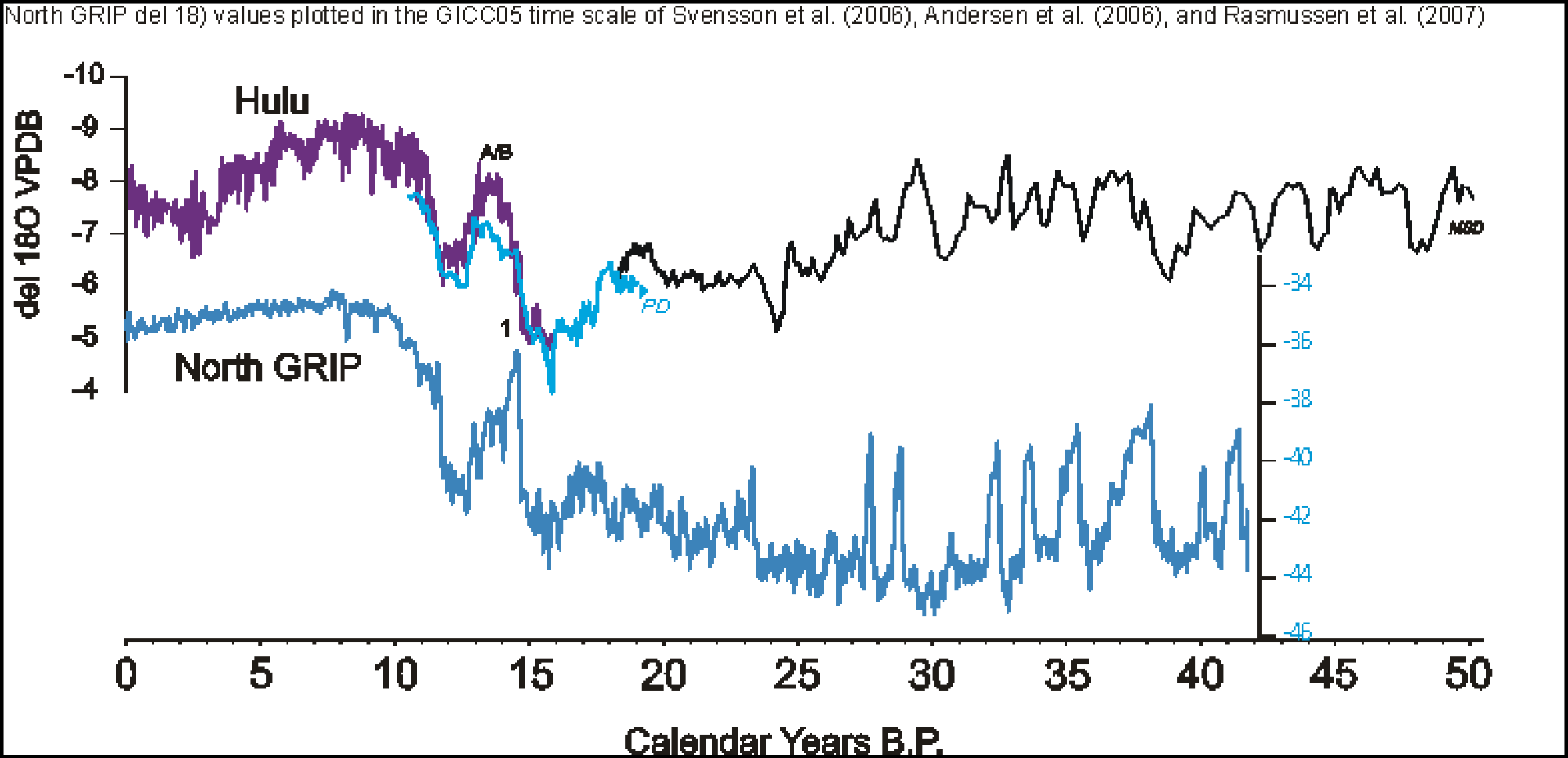






Anton et al (2010) Quaternary Science Reviews

Chinese cave del^{18}O record is the new darling of paleoclimatologists



???why should the Chinese cave records of monsoonal rainfall correlate to temperature history of Greenland???

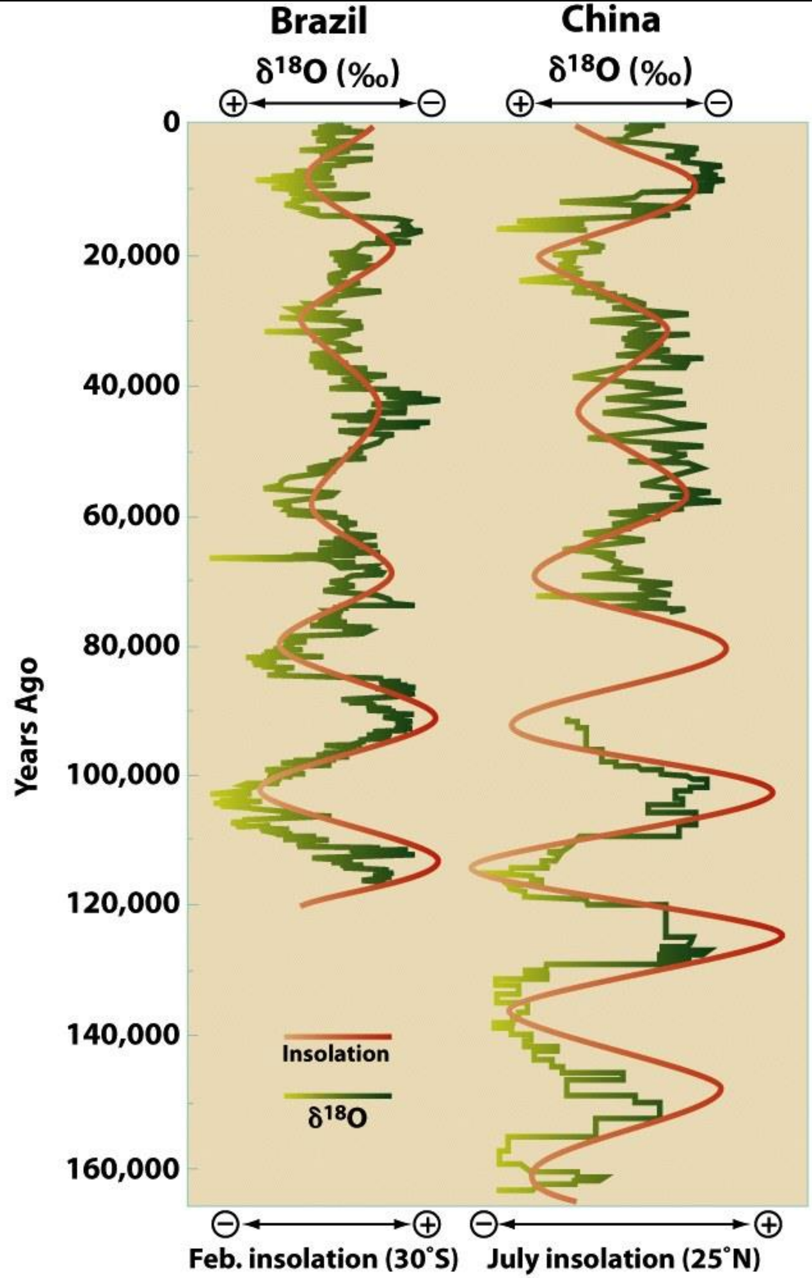


Figure 8-12
Earth's Climate: Past and Future, Second Edition

Green lines show del ^{18}O in calcite cave deposits.

The del ^{18}O variations correlate with precession-driven peaks in midsummer solar insolation in each polar hemisphere.

CHAPTER 9

Insolation Control of Monsoons by the 23,000-year, precession of the equinoxes, Milankovitch cycle

Ruddiman uses monsoon history to illustrate the powerful role of orbital variations in controlling Earth’s climate.

orbital monsoon hypothesis: changing solar insolation affects the strength and extent of monsoon systems

John Kutzbach
Professor Emeritus
Center for Climatic Research
University of Wisconsin

Rudolf Ferdinand Spitaler
Austrian Astronomer
1849-1946

Lahore, Pakistan